21 DECEMBER 2022

15:00 CET

IWA Specialist Group on Modelling and Integrated Assessment Webinar Series

Modelling of phototrophic systems for resource recovery from wastewater

Speakers

Ulf Jeppsson
Lund University

Francisco Gabriel Acién Fernández
Universidad de Almería

Francesca Casagli
Inria

Borja Valverde-Pérez
DTU Sustain

Gabriel Capson-Tojo
INRAE

Elena Ficara
Politecnico di Milano

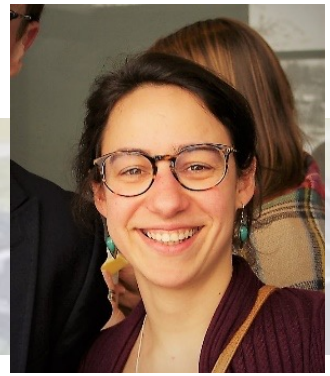
The webinar is going to be recorded and shared on the MIA SG Youtube channel afterward.

MIA Welcome Note

IWA Modelling and Integrated Assessment Specialist Group

Dr. Ulf Jeppsson (Chair of MIA SG)

Dr. Elena Torfs (Vice-chair of MIA SG)



inspiring change

Lund University

Ghent University

MODELLING AND INTEGRATED ASSESSMENT SPECIALIST GROUP (MIA SG)

"This group targets people from research, consulting companies, institutions and operators to think along ***the use of models and computing tools to support the understanding, management and optimization of water systems****."*

PRIORITIES

- Interact with other IWA SGs and other professional organizations
- Organize specialized conferences, sessions and workshops
- Engage and activate YWPs in the domain.

CURRENTLY 1900 MEMBERS

How to find us

Website: http://iwa-mia.org/

https://iwa-connect.org

MIA SG: ACTIVITIES

Task Groups (TGs)

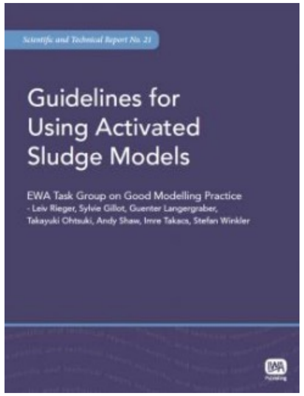
- Benchmarking of Control Strategies (BSM) AND Good Modelling Practice (GMP) AND Design and Operations Uncertainty (DOUT) AND Use of Modelling for Minimizing GHG Emissions (GHG) AND Generalised Physicochemical Modelling (PCM) (all five finished)
- Membrane Bioreactor Modelling and Control (MBR)
- Good Modelling Practice in Water Resource Recovery Systems (GMP2)

Working Groups (WGs)

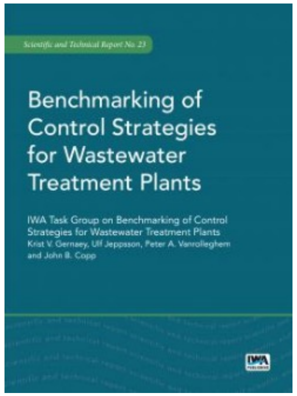
- Integrated Urban Water Systems (IUWS)
- Computational Fluid Dynamics (CFD)
- Good Modelling Practice (GMP)

Conferences / Events

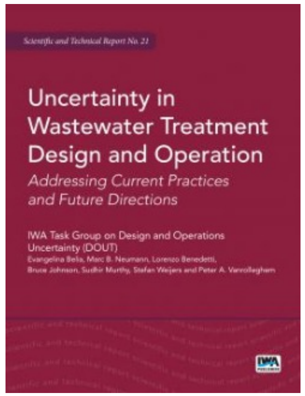
- WRRmod
- Watermatex



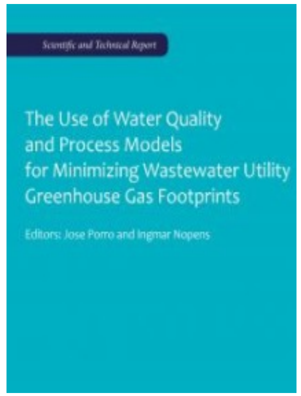
STR (2012)



STR (2014, open access)

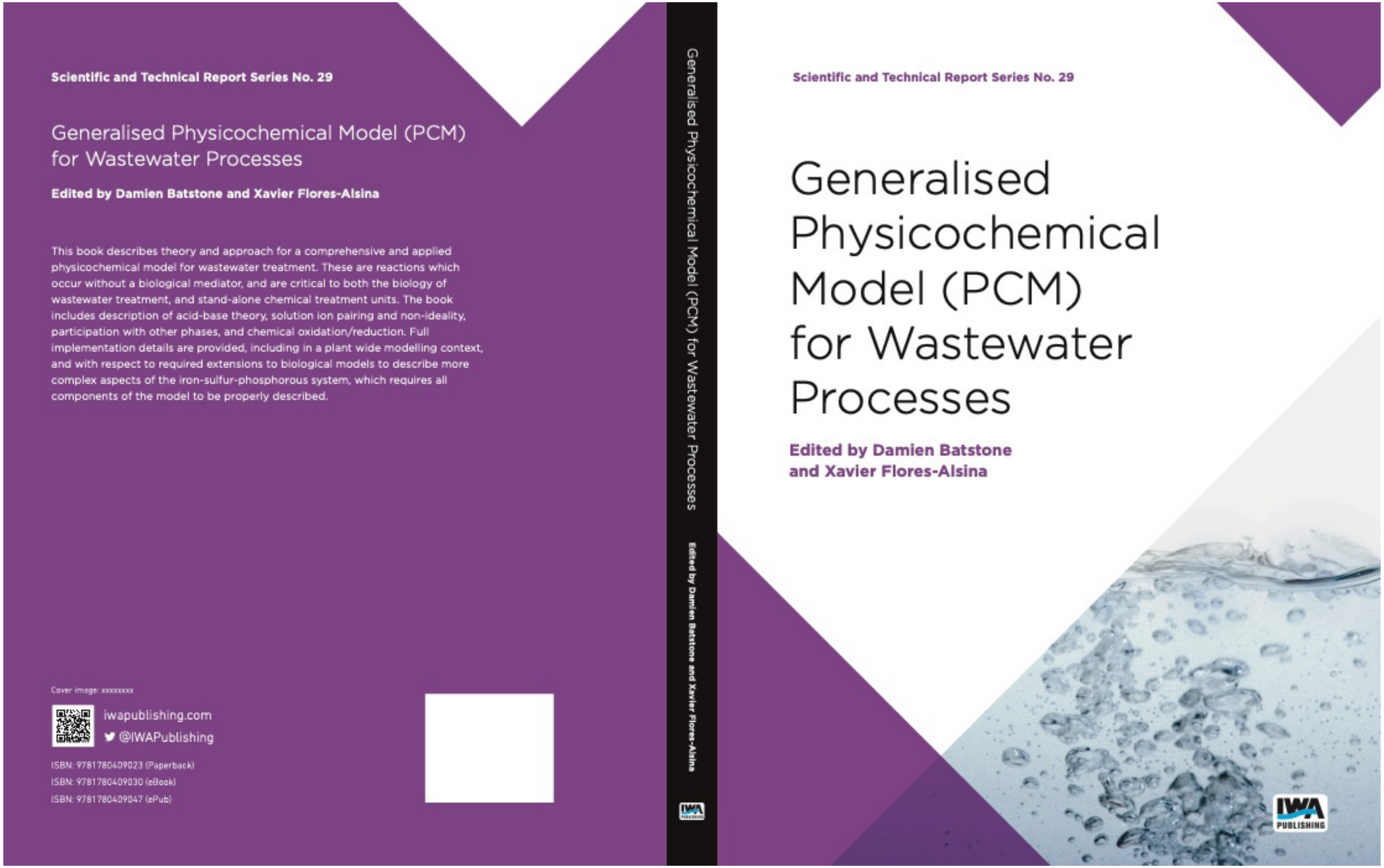


STR (2021, open access)



STR (2022, open access)

JUST PUBLISHED: PCM STR – OPEN ACCESS



MIA SG: UPCOMING CONFERENCES

8th Water Resource Recovery Modelling seminar (WRRmod2022+)

- Location: Stellenbosch, South Africa, 18-21 January 2023
- Chair: Dr. David Ikumi (Univ. Cape Town)

11th Symposium on Modelling and Integrated Assessment (Watermatex2023)

- Location: Québec City, Canada, 23-27 Sept. 2023
- Chair/vice-chair: Prof. Peter Vanrolleghem (Univ. Laval)/Dr. Elena Torfs (Univ. Ghent)

9th Water Resource Recovery Modelling seminar (WRRmod2024), PROBABLY in Stowe, Vermont, USA

FIND MIA SG ON SOCIAL MEDIA

Follow the Modelling and Integrated Assessment Specialist Group on:

- IWA Connect https://iwa-connect.org/group/modelling-and-integrated-assessment-mia/timeline
- https://www.linkedin.com/company/iwa-mia-specialist-group-on-modelling-and-integrated-assessment
- https://twitter.com/iwa_mia_sg
- **MIA SG open web site** http://iwa-mia.org

to get informed about our latest events, publications and news!

Newsletter, push messages, webinars, YouTube channel, digital archive

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INTRODUCTION

Elena Ficara *(Politecnico di Milano, Italy)*

Environmental Engineer, PhD in Sanitary Engineering,
Associate professor at POLIMI - Dept. of Civil and Environmental Eng.

Topics: biological processes for bioremediation and resource recovery from urban and agro-industrial waste streams (nitrifiers, anammox, anaerobic digestion, microalgae), monitoring, modelling for process optimization

PHOTOTROPHS (MICROALGAE, PURPLE BACTERIA)

Newcomers as organisms of interest in wastewater treatment

- converting solar radiation into organics, and high-value molecules,
- CO_2 capture and utilization, photo-oxygenation
- contributing to bioremediation: assimilating nutrients, micropollutants removal, disinfection

New challenges for the process engineers and for the modelling community

- New metabolic pathways (light dependent growth)
- Relevant specific phyco-chemical phenomena (light penetration, light dependent growth)
- Interaction with other microorganisms in open systems
- Different/specific fluidodynamics for photobioreactors

AGENDA

Speaker 1
Francisco Gabriel Acién Fernández (Universidad de Almería, Spain)
Microalgae based nutrients recycling processes

Speaker 2
Francesca Casagli (INRIA, Italy)
Algae-bacteria systems for nitrogen recovery and biomass production: promises and challenges through a modelling approach

Speaker 3
Borja Valverde-Pérez (Technical University of Denmark)
Modeling light distribution in photobioreactors and its impact on algal growth

Speaker 4
Gabriel Capson-Tojo (INRAE, France)
Modelling outdoors systems based on Purple Phototrophic Bacteria for resource recovery

Q&A Session Moderator: *Elena Ficara (Politecnico di Milano, Italy)*

AGENDA AND HOUSEKEEPING

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This project is funded by the European Union

SABANA
Sustainable Algae Biorefinery for Agriculture aNd Aquaculture

Microalgae based nutrients recycling processes

UNIVERSIDAD DE ALMERÍA

Prof. F. Gabriel Acien (facien@ual.es)

Dpt. Chemical Engineering, University of Almeria, SPAIN

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

This project has received funding from the European Union's Horizon 2020 Research and Innovation program under the Grant Agreement No. 727874

This project is funded by the European Union

Project information

Project description

Development of microalgae based sustainable processes to transform wastewater into valuable products for agriculture and aquaculture

Sustainable Algae Biorefinery for Agriculture aNd Aquaculture (SABANA)	
Call	H2020-BG-2016-2017 Blue Growth
Organism	European Commission
Topic/Type/Budget	BG-01-2016, Innovation action, 10,5 M€
Duration (months)	2017-2021

This project is funded by the European Union

Feedstock

Wastewater as nutrients source

The composition of sewage and centrate are similar to standard microalgae culture media, but digestate and manure contain too much contaminants

Effluent	COD/BOD, mg/l	N, mg/l	P, mg/l	Total Suspended Solids, mg/l	Turbidity, NTU	Biomass production, kg/m^3
Digestate	9000/7000	8000	400	10000	30000	**100.0**
Manure	16000/12000	9000	500	3000	9000	**112.5**
Agro-industrial (Breweries)	4000/3800	30	10	1000	3000	**0.4**
Centrate	300/200	500	12	1000	3000	**6.3**
Sewage	700/500	65	11	300	900	**0.8**
Microalgae culture medium		**50**	**10**	**0**	**0**	

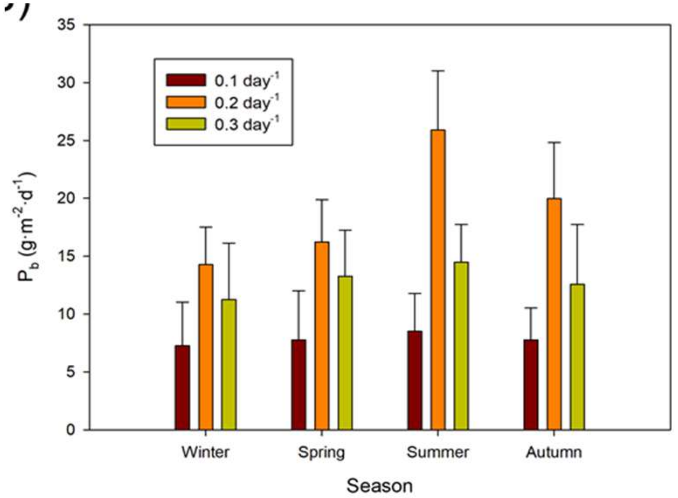
Microalgae can be produced using whatever of these wastewater as only nutrients source, recovering up 90% of nutrients inlet

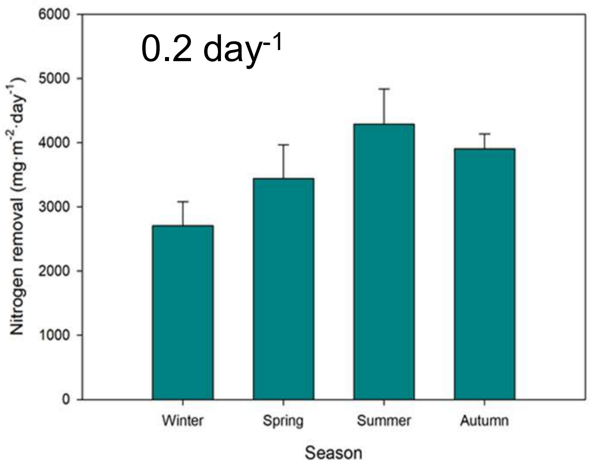
This project is funded by the European Union

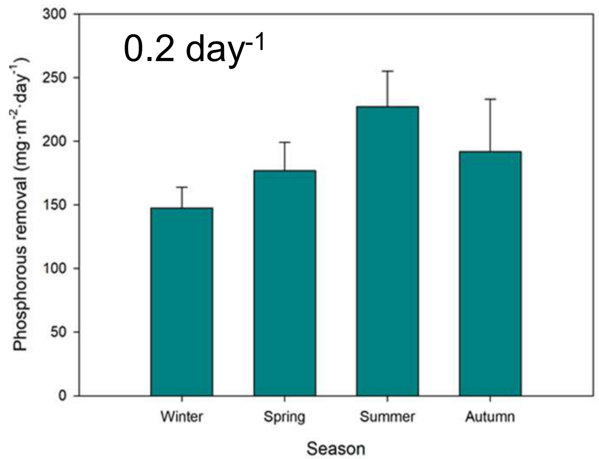
Technological apporach

Year-long evaluation of microalgae production using wastewater

BOD is always removed but N/P is only removed when maximizing productivity







Mean values on annual basis:

- Wastewater treatment = 400 m^3/ha·day
- Biomass production = 200 kg/ha·day
- BOD removal = 200 kg/ha·day
- N removal = 35 kg/ha·day
- P removal = 1.8 kg/ha·day
- Complete accomplishment of regulation (BOD, N, P)

This project is funded by the European Union

Technological apporach

SABANA

Firsts industrial demonstrators

aqualia

20,000m²

10,000m²

22,200m²

3,000m²

All-gas biosol water recycling SABANA INCOVER

This project is funded by the European Union

Technological apporach

Firsts industrial demonstrators

F (m^3/d)	1000
TN (ppm)	50.4±8
TP (ppm)	10.3±3
COD (mgO_2/L)	525±120

F	940.1
TN	12.0±2
TP	6.3±1,8
TSS	500+150

TN	12.0± 2,2
TP	1.01±0,75
COD	80.2±20
TSS	25.4±7,5

110±32
Ton/Ha yr

Simultaneous COD, TN and TP removal , 80%, 74% and 88%, respectively

Energy requirement 0,17kWh/m^3

2 to 3 m^2/PE

Simple process:
No external carbon
Single stage

Biomass rich in:
N and P

This project is funded by the European Union

Obtained products

5000 PE
Simultaneous
N, P, COD & TSS removal
Below directive 91/271/EC

Firsts industrial demonstrators

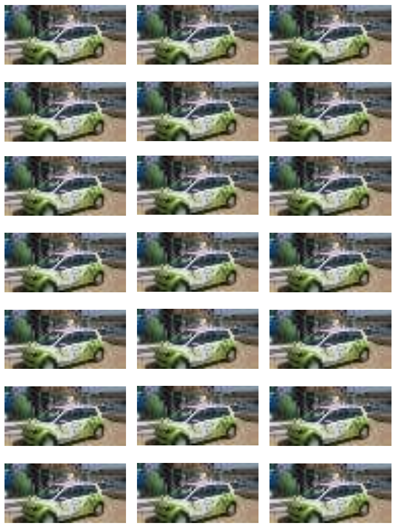
1000 m^3/d WW

950 m3/d Reuse

40-60 Ton/ yr biomass

1 hectare

15 000 kg / 4,5 =
330.000 km
15 000 km/yr
22 cars



13,000 kg CH4/yr

- 0,3kWh/m3

Energy saving
106.800
kWh/yr

50-60% VS
bio-CH4

>100 Ton/ yr

aqualia industrial

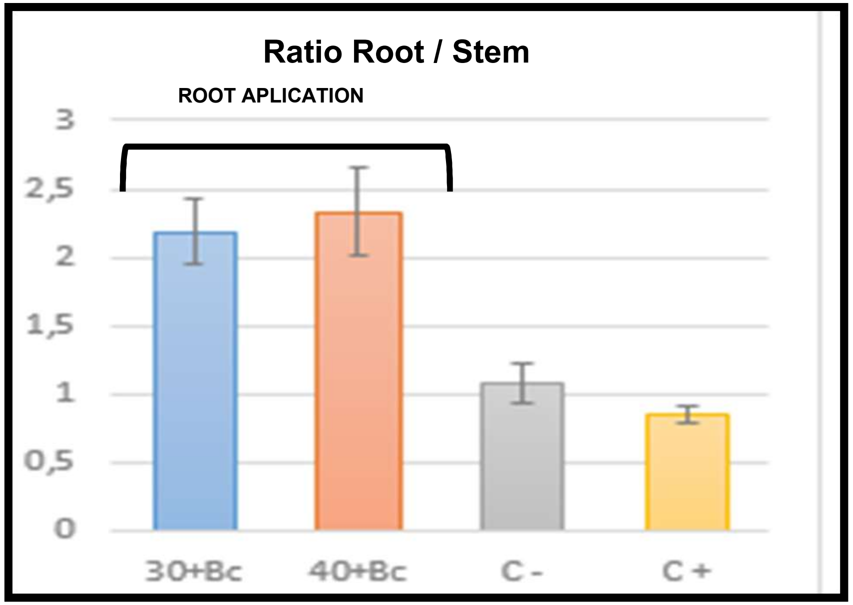
This project is funded by the European Union

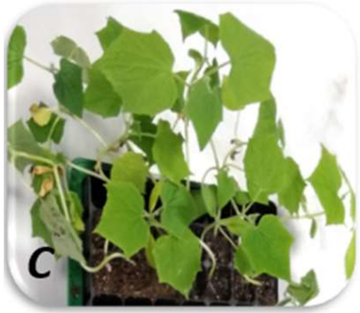
Obtained products

SABANA
Sustainable Algae Biorefinery for Agriculture aNd Aquaculture

Agriculture applications

Protective effect





- **Higher productivity/quality (>20%)**
- **Reduction on fertilizers consumption (<10%)**
- **Reduction of fungi adverse effects (>40%)**
- **Larger root development and tolerance to stress factors**

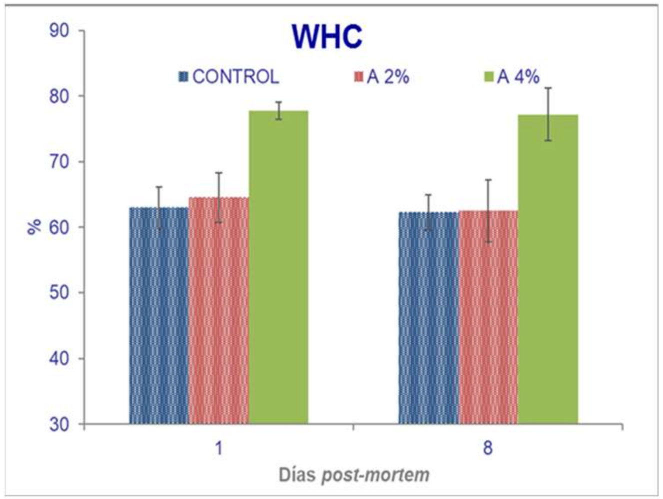
This project is funded by the European Union

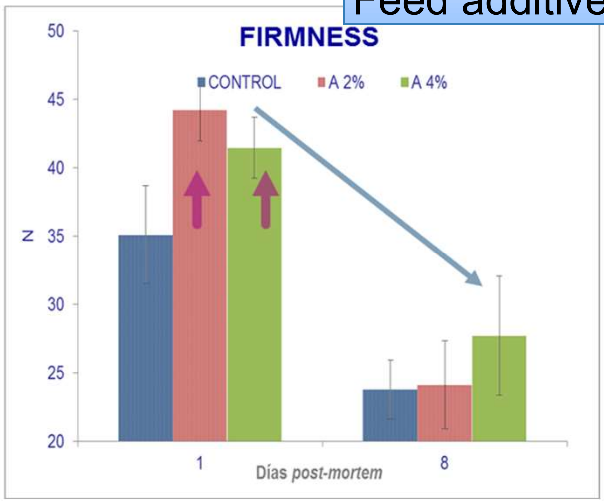
Obtained products

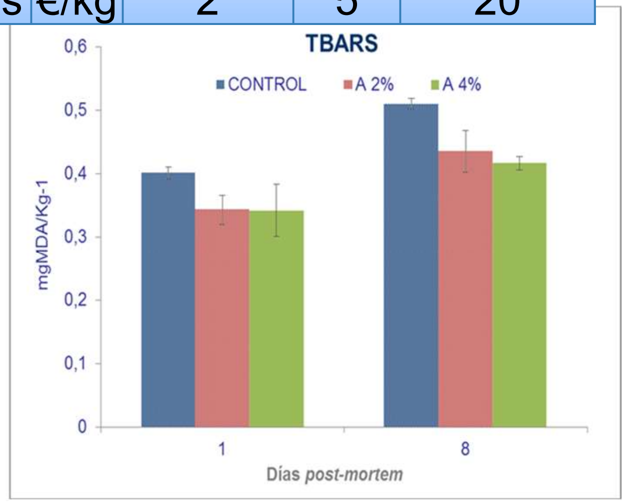
Aquaculture applications

Effect of fish flesh quality

		Regular	High	Premium
Aquafeed	€/kg	1	3	10
Feed additives	€/kg	2	5	20







- Improve Water Holding Capacity (WHC) in fillet during storage.
- Texture Profile Analysis (TPA): Increase in firmness of fish fillet.
- Lower level of lipid peroxidation in fillet, even during storage for eight days

SABANA

Sustainable Algae Biorefinery for Agriculture aNd Aquaculture

www.eu-sabana.eu | info@sabana.eu

sabana.eu

@sabana.eu

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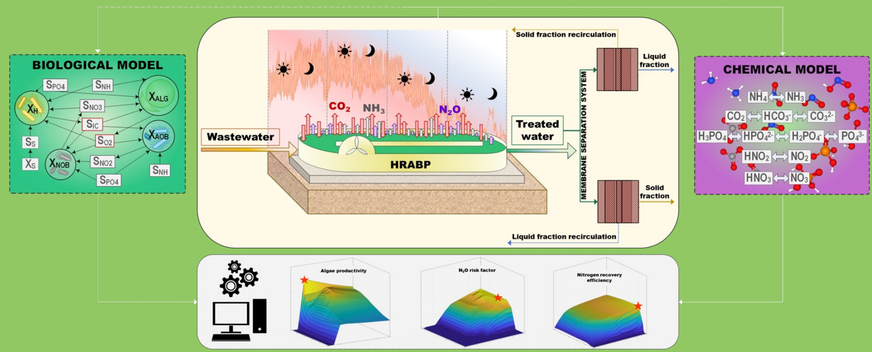
Francesca CASAGLI

Algae-bacteria systems for nitrogen recovery and biomass production: promises and challenges through a modelling approach



IWA Specialist Group on Modelling and Integrated Assessment Webinar:
“Modelling of phototrophic systems for resource recovery from wastewater”

21/12/2022

ALGAE/BACTERIA - BASED BIOREMEDIATION

Climatology

Wastewater Nutrients (C,N,P)

CO_2, Off-Gas

Treated water

Emissions (CO_2, NH_3, N_2O)

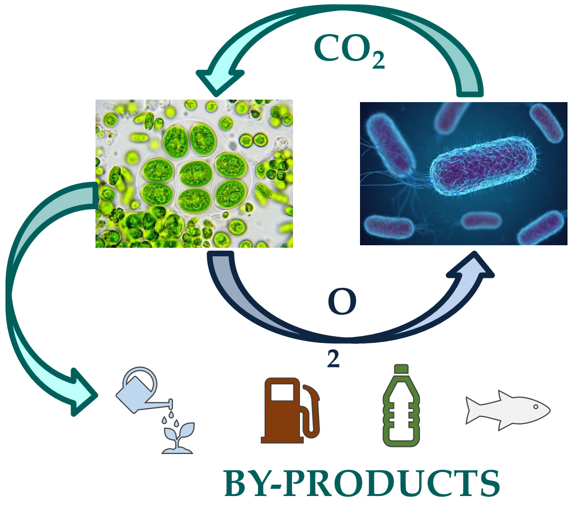
Algal Biomass

BY-PRODUCTS

ALGAE-BACTERIA SYSTEM ADVANTAGES & BOTTLENECKS

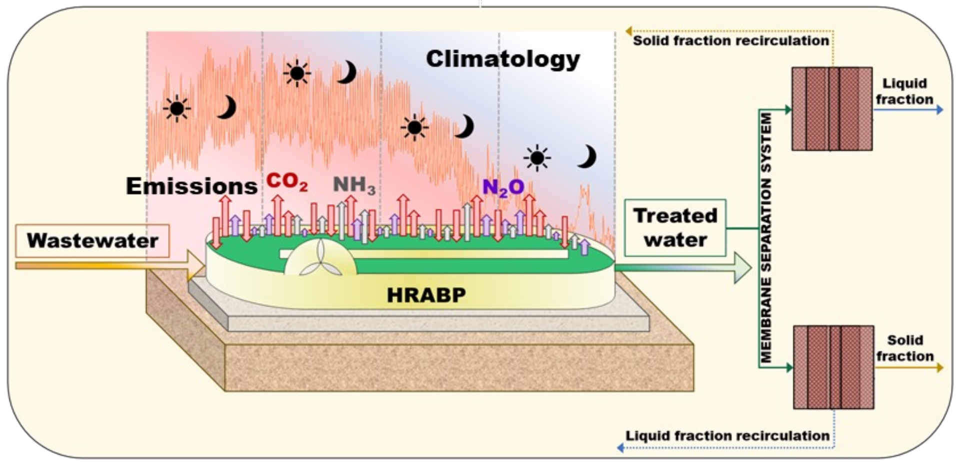
Main advantages

- Recycling energy, nitrogen and phosphorus
- Production of valuable products (circular economy)
  - Biofuels
  - Biofertilizers
  - Biomaterials
- Reduced costs for aeration systems



Main bottlenecks

- Outdoor ecosystems → local climatology driving the bioprocess efficiency → unravelling optimal management and design
- Solid-liquid separation → uncoupling HRT and SRT
- Emissions (CO_2, NH_3, N_2O) and inorganic carbon limitation

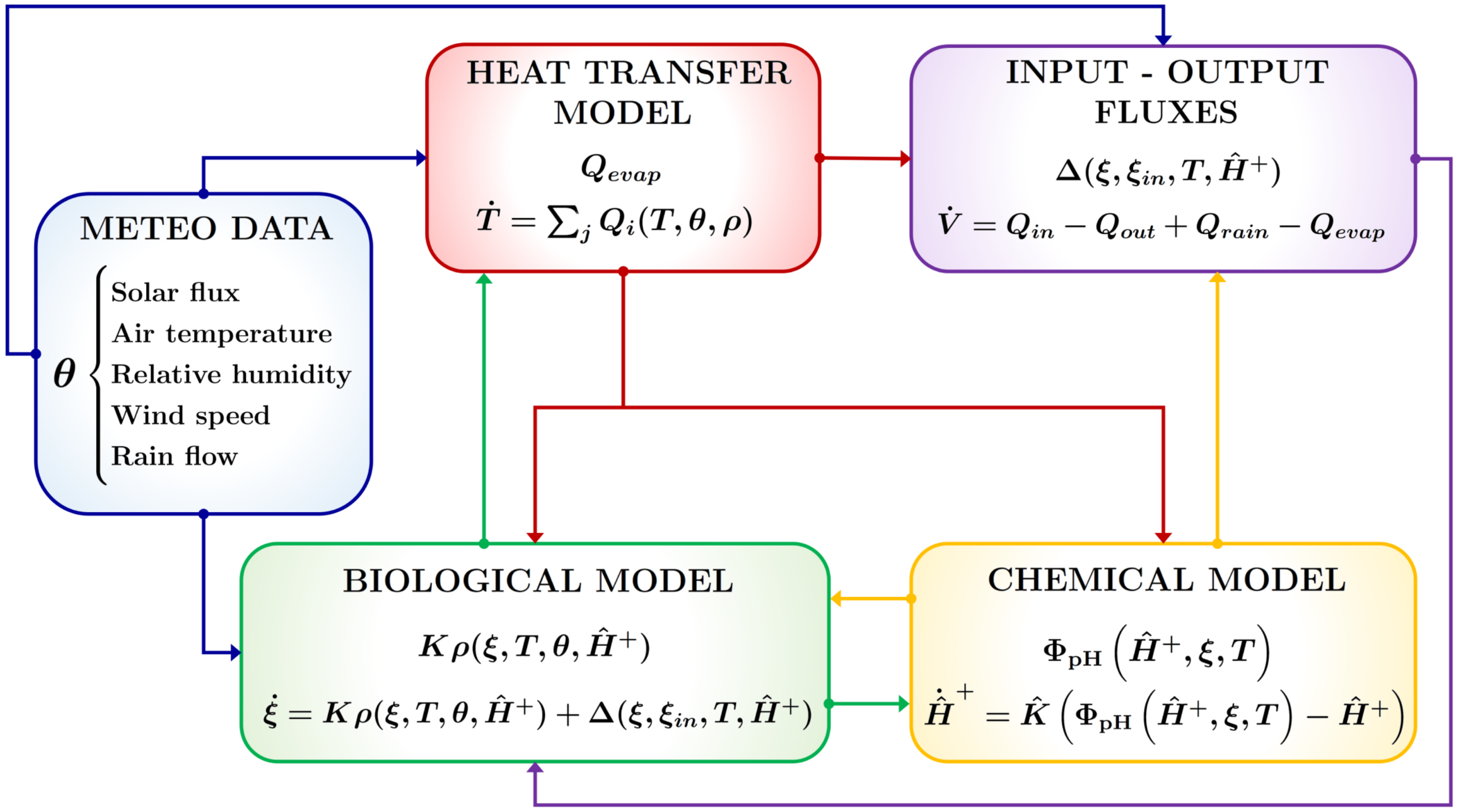


MODELLING CHALLENGES

- Consider together biological, chemical and physical aspects
- Validating the model on a long run, including all the seasons
- Quantifying the emissions / fluxes.
- Accounting for a separation system
- Identifying the process limitations

In other words…understanding the invisible

BIOLOGICAL – PHYSICAL - CHEMICAL FRAMEWORK STRUCTURE



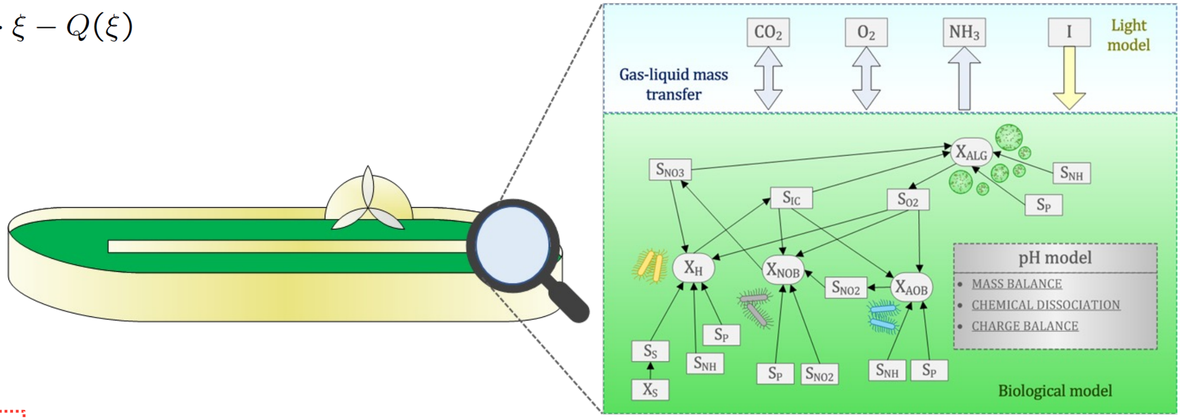
BIOLOGICAL MODEL

$$\begin{cases} \dot{\xi} = K^T \cdot \rho(\xi) + \dfrac{Q_{in}}{V} \cdot \xi_{in} - \dfrac{Q_{in} + Q_{rain} - Q_{evap}}{V} \cdot \xi - Q(\xi) \\ \dot{V} = Q_{in} - Q_{out} \end{cases}$$

BIOLOGICAL MODEL

$$K\rho(\xi, T, \theta, \hat{H}^+)$$

$$\dot{\xi} = K\rho(\xi, T, \theta, \hat{H}^+) + \Delta(\xi, \xi_{in}, T, \hat{H}^+)$$



ξ	state variable vector - 17 state variables [g m^{-3}];
ξ_{in}	vector of influent concentrations [g m^{-3}]
$\rho(\xi)$	vector of reaction rates - 19 biological processes [g m^{-3} d^{-1}];
Q_{in}	inflow rate [m^3 d^{-1}]
$Q(\xi)$	gaseous exchanges with atmosphere (O_2, CO_2, NH_3) [g m^{-3} d^{-1}]
$P = K^T$	stoichiometric matrix (Petersen matrix according to ASMs and ADM1 structure)

$X_{BM,i}$ = biomasses (**X_{ALG}, X_H, X_{AOB}, X_{NOB}**)

X_i = particulate organic matter (**X_S, X_I**)

S_i = soluble compounds (**S_S, S_I, S_{NH}, S_{NO2}, S_{NO3}, S_{N2}, S_{ND}, S_{IC}, S_{PO4}, S_{O2}, S_{H2O}, S_{H+}**)

$$\rho_j = \mu_{max_j}(T, pH) \cdot \frac{1}{h}\int_0^h \mu(I(I_0, z))dz \cdot \frac{K_n}{K_n + S_n} \cdot \min_i\left(\frac{S_i}{S_i + K_{S_i}}\right) \cdot X_{BM_i}$$

$$Q_j = k_L a_j(T_R) \cdot \left(\frac{D_{S_j}}{D_{S_{O_2}}}\right)^{0.5} \cdot (S_{j,sat}(T_R) - S_j)$$

Simplified model for N_2O fluxes predictions

$$\text{Flux } N_2O = \psi \cdot X_{AOB} \cdot \frac{CO^n_{2,T}}{CO^n_{2,T} + CO^n_2}$$

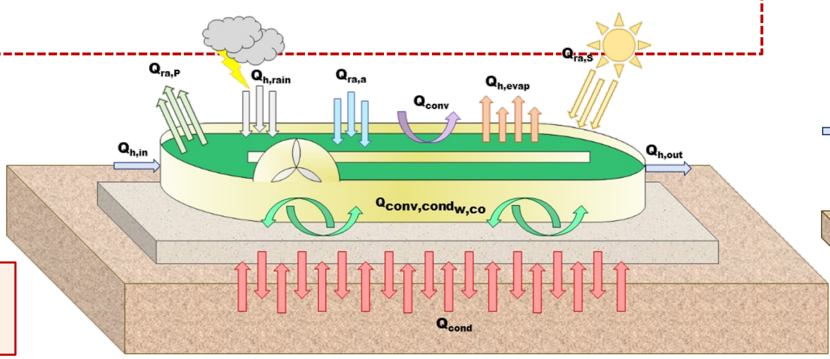
HEAT TRANSFER MODEL

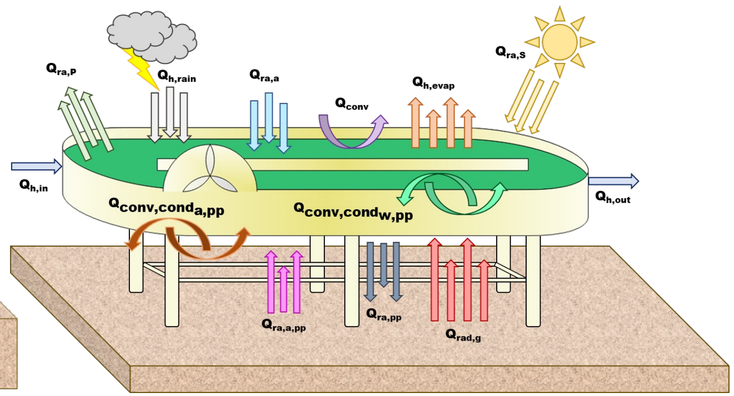
HEAT TRANSFER MODEL

Q_{evap}

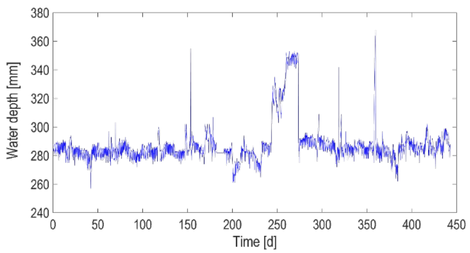
$\dot{T} = \sum_j Q_i(T, \theta, \rho)$

$$\rho_w V C_{p,w} \frac{dT_R}{dt} = Q_{ra,p} + Q_{ra,s} + Q_{ra,a} + Q_{h,evap} + Q_{conv} + Q_{h,in} + Q_{h,out} + Q_{h,rain} - Q_{conv,cond_w,i}$$





LIQUID DEPTH VARIATION:



$$Q_{conv,cond_w,co} = h_{w,co} \cdot (T_R - T_{co})S$$

$$\rho_{co} V_{co} C_{p,co} \frac{dT_{co}}{dt} = Q_{conv,cond_w,co} + Q_{cond}$$

$$Q_{conv,cond_w,pp} = h_{w,pp} \cdot (T_p - T_{pp})S$$

$$Q_{conv,cond_a,pp} = h_{a,pp} \cdot (T_a - T_{pp})S$$

$$\rho_{pp} V_{pp} C_{p,pp} \frac{dT_{pp}}{dt} = Q_{conv,cond_w,pp} + Q_{conv,cond_a,pp} + Q_{ra,pp} + Q_{ra,a,pp} + Q_{rad,d}$$

CHEMICAL MODEL

CHEMICAL MODEL

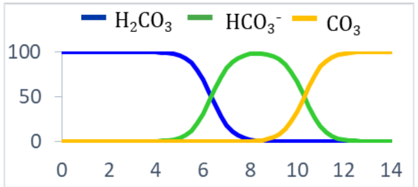
$$\Phi_{\mathrm{pH}}\left(\hat{H}^{+},\xi,T\right)$$

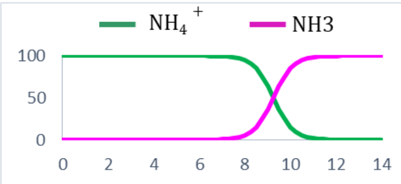
$$\dot{\hat{H}}^{+} = \hat{K}\left(\Phi_{\mathrm{pH}}\left(\hat{H}^{+},\xi,T\right) - \hat{H}^{+}\right)$$

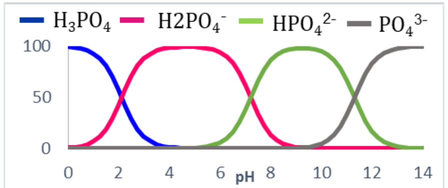
1) MASS BALANCE ON DISSOCIATED SPECIES

2) DISSOCIATION OF SOLUBLE SPECIES

3) CHARGE BALANCE:







Description	Expression $[molm^{-3}]$
	Ammoniacal nitrogen
1) Mass balance	$\frac{S_{NH}}{14} - NH_3 - NH_4^+ = 0$
2) Dissociation	
$NH_4^+ \rightleftharpoons NH_3 + H^+$	$NH_4^+ - \frac{S_{NH}/14}{1+\frac{Ka_{NH_4}10^3}{H^+}} = 0$
	Nitrogen oxides
3) Mass balance	$\frac{S_{NO_2}}{14} - NO_2^- - HNO_2 = 0$
4) Dissociation	
$HNO_2 \rightleftharpoons NO_2^- + H^+$	$HNO_2 - \frac{S_{NO_2}/14}{1+\frac{Ka_{HNO_2}10^3}{H^+}} = 0$
5) Mass balance	$\frac{S_{NO_3}}{14} - NO_3^- - HNO_3 = 0$
6) Dissociation	
$HNO_3 \rightleftharpoons NO_3^- + H^+$	$HNO_3 - \frac{S_{NO_3}/14}{1+\frac{Ka_{HNO_3}10^3}{H^+}} = 0$
	Inorganic carbon
7) Mass balance	$\frac{S_{IC}}{12} - CO_2 - HCO_3^- - CO_3^{2-} = 0$
8) Dissociation	
$H_2O + CO_2 \rightleftharpoons HCO_3^- + H^+$	$CO_2 - \frac{S_{IC}/12}{1+\frac{Ka_{CO_2}10^3}{H^+}+\frac{Ka_{CO_2}Ka_{HCO_3}10^6}{(H^+)^2}} = 0$
9) Dissociation	
$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$	$HCO_3^- - \frac{S_{IC}/12}{1+\frac{H^+}{Ka_{CO_2}10^3}+\frac{Ka_{HCO_3}10^3}{H^+}} = 0$
	Ortophosphates
10) Mass balance	$\frac{S_{PO_4}}{31} - H_3PO_4 - H_2PO_4^- - HPO_4^{2-} - PO_4^{3-} = 0$
11) Dissociation	
$H_3PO_4 \rightleftharpoons H_2PO_4^- + H^+$	$H_3PO_4 - \frac{S_{PO_4}/31}{1+\frac{Ka_{H_3PO_4}10^3}{H^+}+\frac{Ka_{H_3PO_4}Ka_{H_2PO_4}10^6}{(H^+)^2}+\frac{Ka_{H_3PO_4}Ka_{H_2PO_4}Ka_{HPO_4}10^9}{(H^+)^3}} = 0$
12) Dissociation	
$H_2PO_4^- \rightleftharpoons HPO_4^{2-} + H^+$	$H_2PO_4^- - \frac{S_{PO_4}/31}{1+\frac{H^+}{Ka_{H_3PO_4}10^3}+\frac{Ka_{H_2PO_4}10^3}{H^+}+\frac{Ka_{H_2PO_4}Ka_{HPO_4}10^6}{(H^+)^2}} = 0$
13) Dissociation	
$HPO_4^{2-} \rightleftharpoons PO_4^{3-} + H^+$	$HPO_4^{2-} - \frac{S_{PO_4}/31}{1+\frac{(H^+)^2}{Ka_{H_3PO_4}Ka_{H_2PO_4}10^6}+\frac{H^+}{Ka_{H_2PO_4}10^3}+\frac{Ka_{HPO_4}10^3}{H^+}} = 0$
14) Dissociation	
$H_2O \rightleftharpoons OH^- + H^+$	$OH^- - \frac{Ka_w 10^6}{H^+}$
15) Charge balance	$H^+ + NH_4^+ + \Delta_{CAT,AN} - OH^- - NO_2^- - NO_3^- - HCO_3^- - 2CO_3^{2-} - H_2PO_4^- - 2HPO_4^{2-} - 3PO_4^{3-} = 0$

TOTAL ALKALINITY

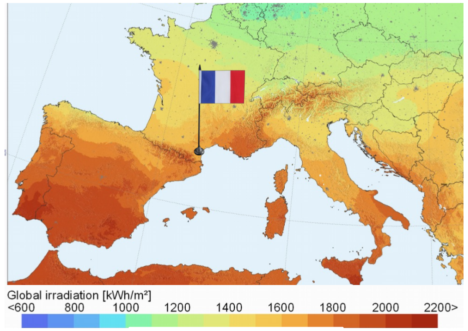
$$TA = HCO_3^- + 2CO_3^{2-} + H_2PO_4^- + HPO_4^{2-} + 2PO_4^{3-} + OH^- + NH_3 - H^+ - HNO_2 - HNO_3 - H_3PO_4$$

Digestate can present significant concentrations of volatile fatty acids (VFA) and H_2S.
In this case, the TA formula should account also for them:

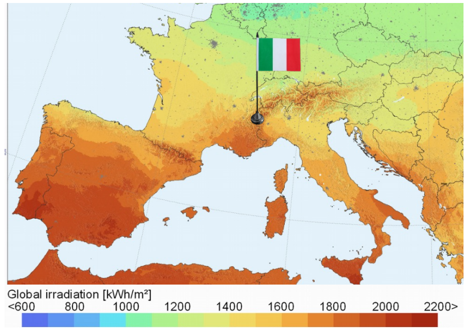
$$TA = HCO_3^- + 2CO_3^{2-} + H_2PO_4^- + HPO_4^{2-} + 2PO_4^{3-} + OH^- + NH_3 + C_2H_3OO^- + C_4H_7OO^- + C_3H_5OO^- + C_5H_9OO^- + HS^- + 2S^{2-} - H^+ - HNO_2 - HNO_3 - H_3PO_4$$

PILOT SCALE APPLICATIONS FOR MODEL CALIBRATION AND VALIDATION

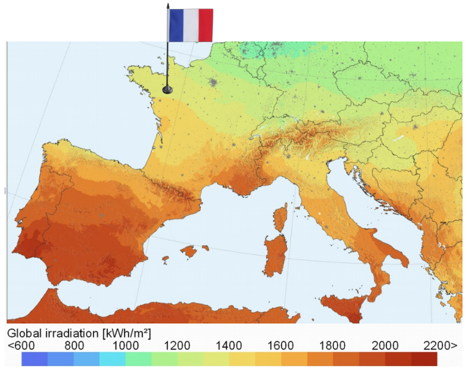
THREE CLIMATOLOGIES TESTED



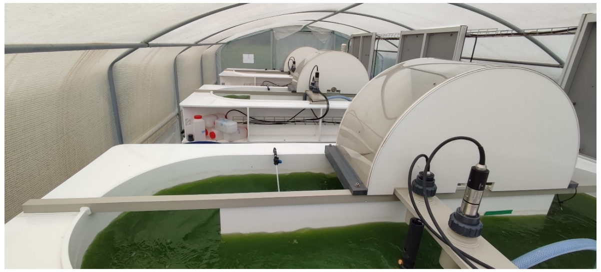
Narbonne



Milan



Rennes



Synthetic WW
443 days

CALIBRATION +
VALIDATION

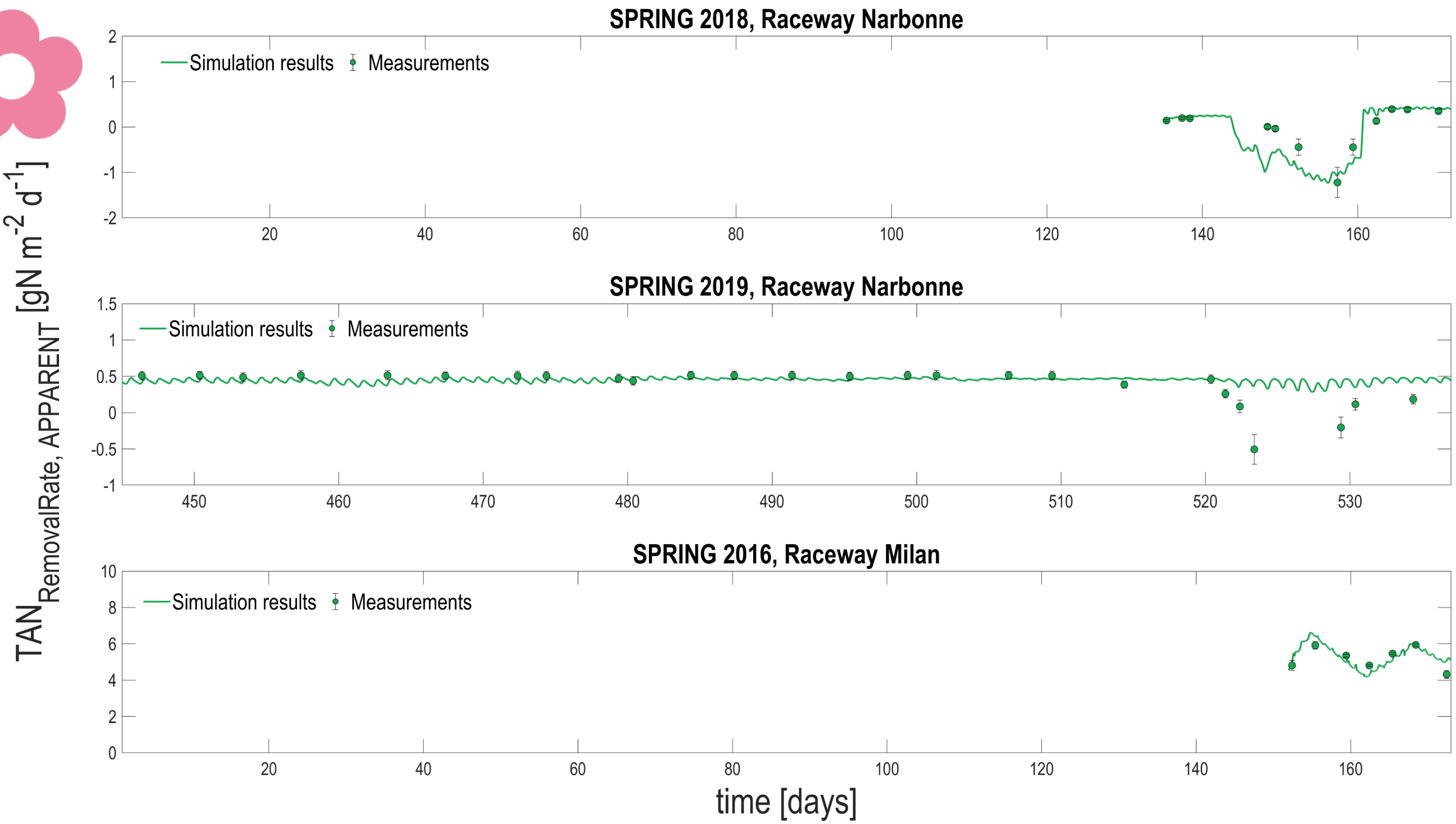
Piggery digestate
189 days

VALIDATION

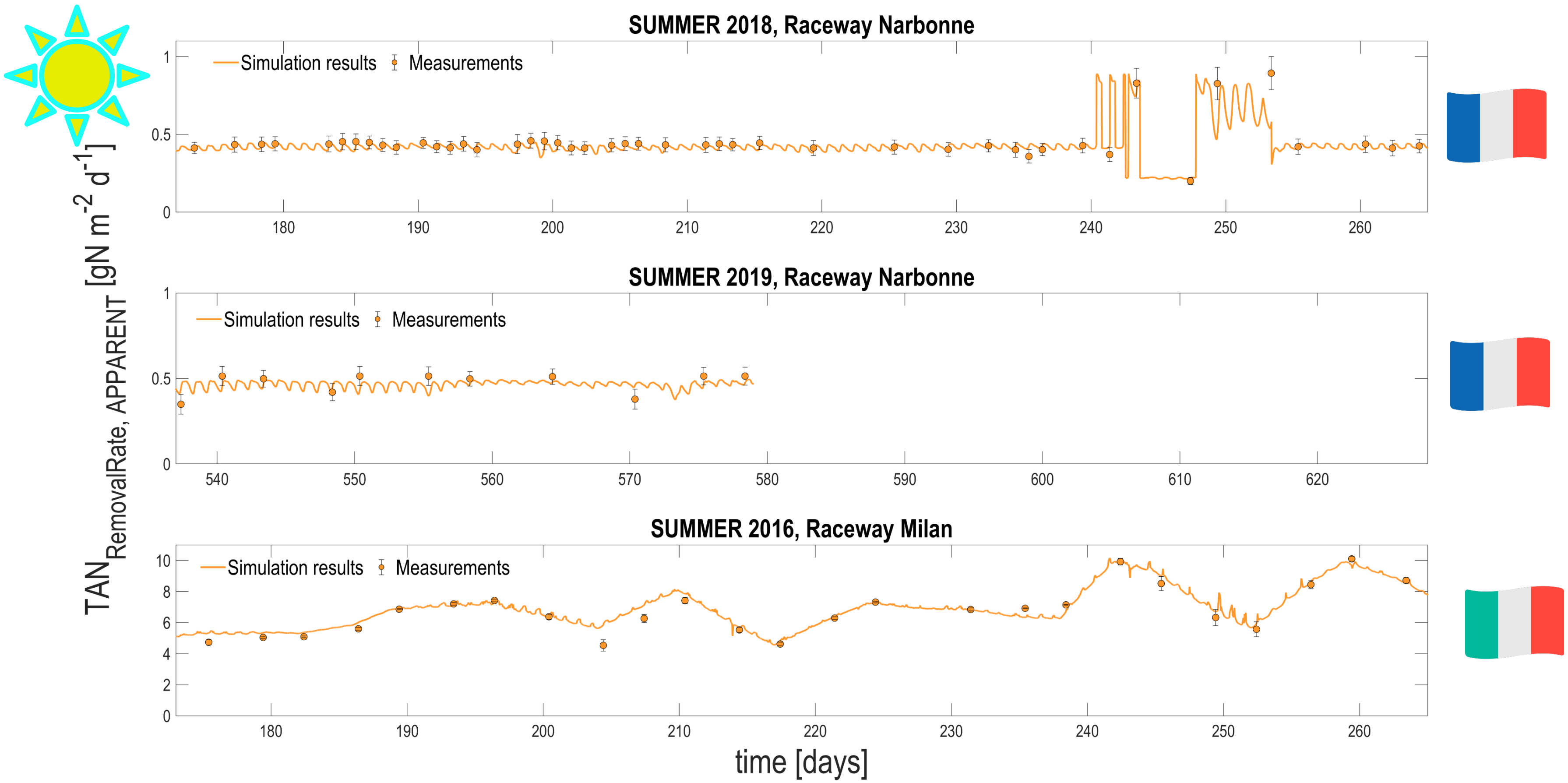
Piggery digestate
14 days

VALIDATION

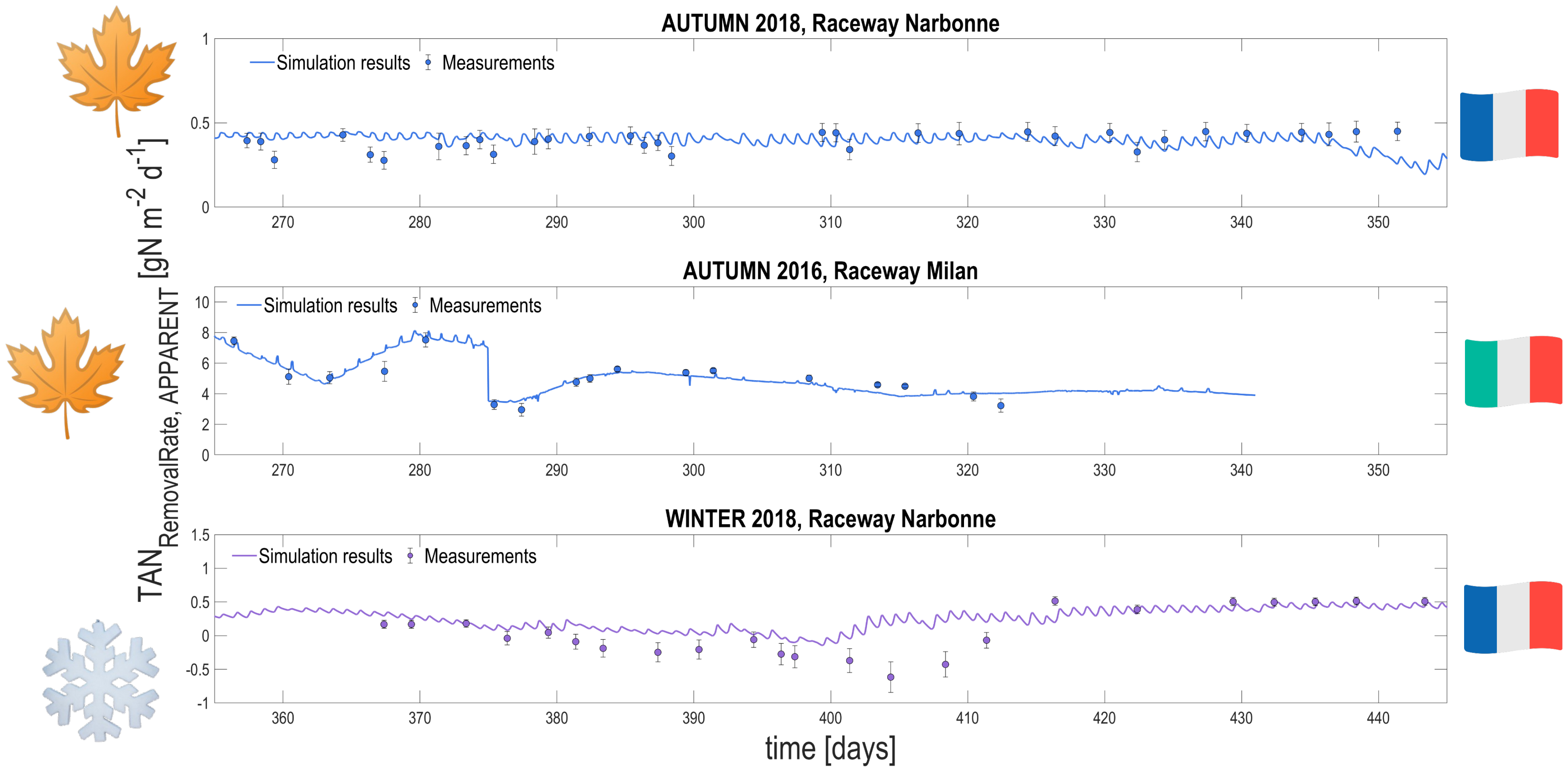
THE ALBA MODEL PREDICTION CAPABILITY: TAN REMOVAL RATE



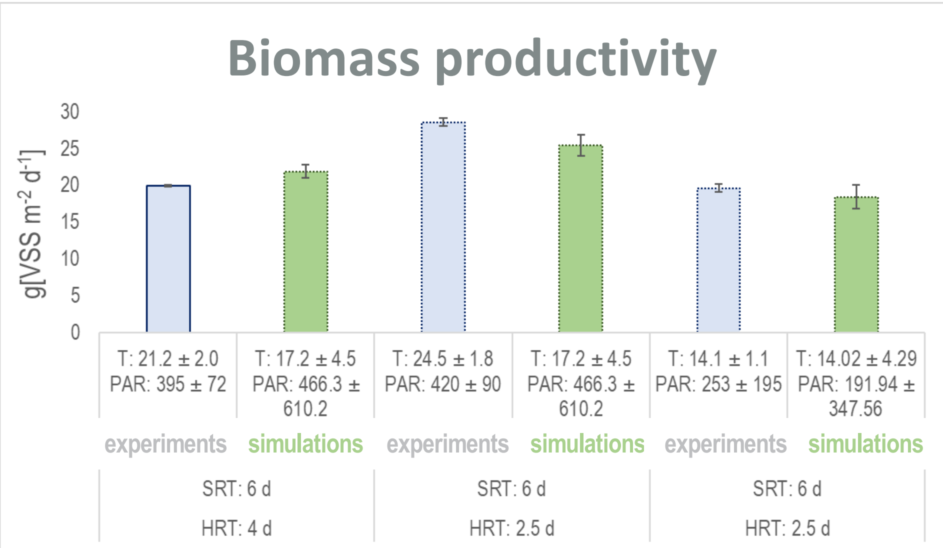
THE ALBA MODEL PREDICTION CAPABILITY: TAN REMOVAL RATE



THE ALBA MODEL PREDICTION CAPABILITY: TAN REMOVAL RATE

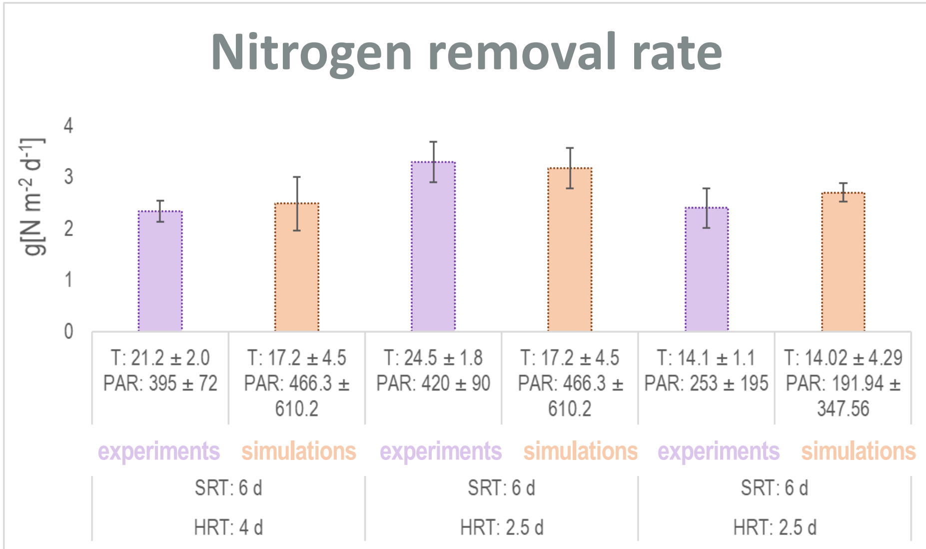


VALIDATION WITH MEMBRANE SEPARATION



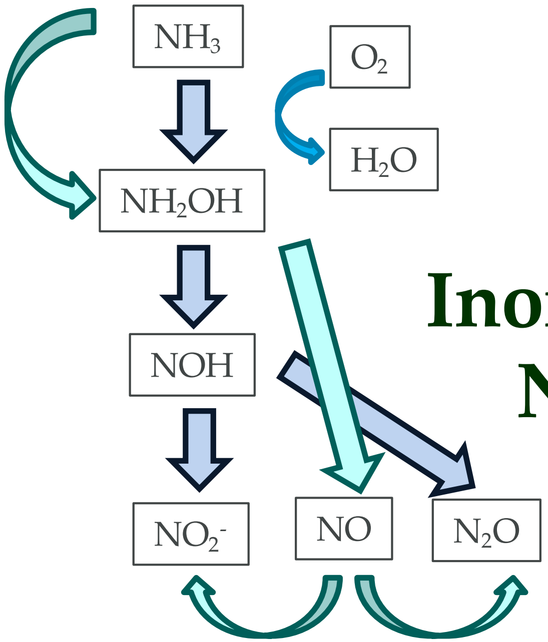
spring spring autumn

R^2=0.78

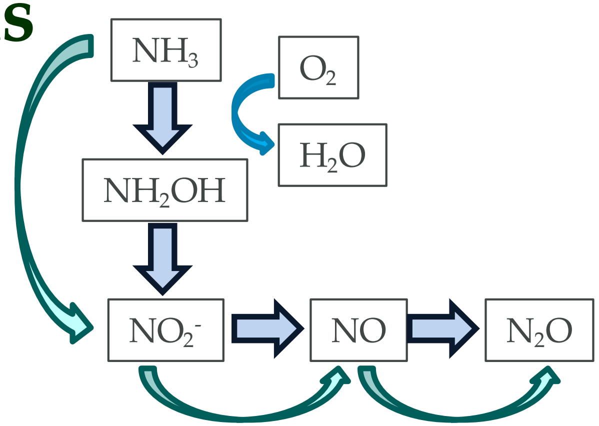


spring spring autumn

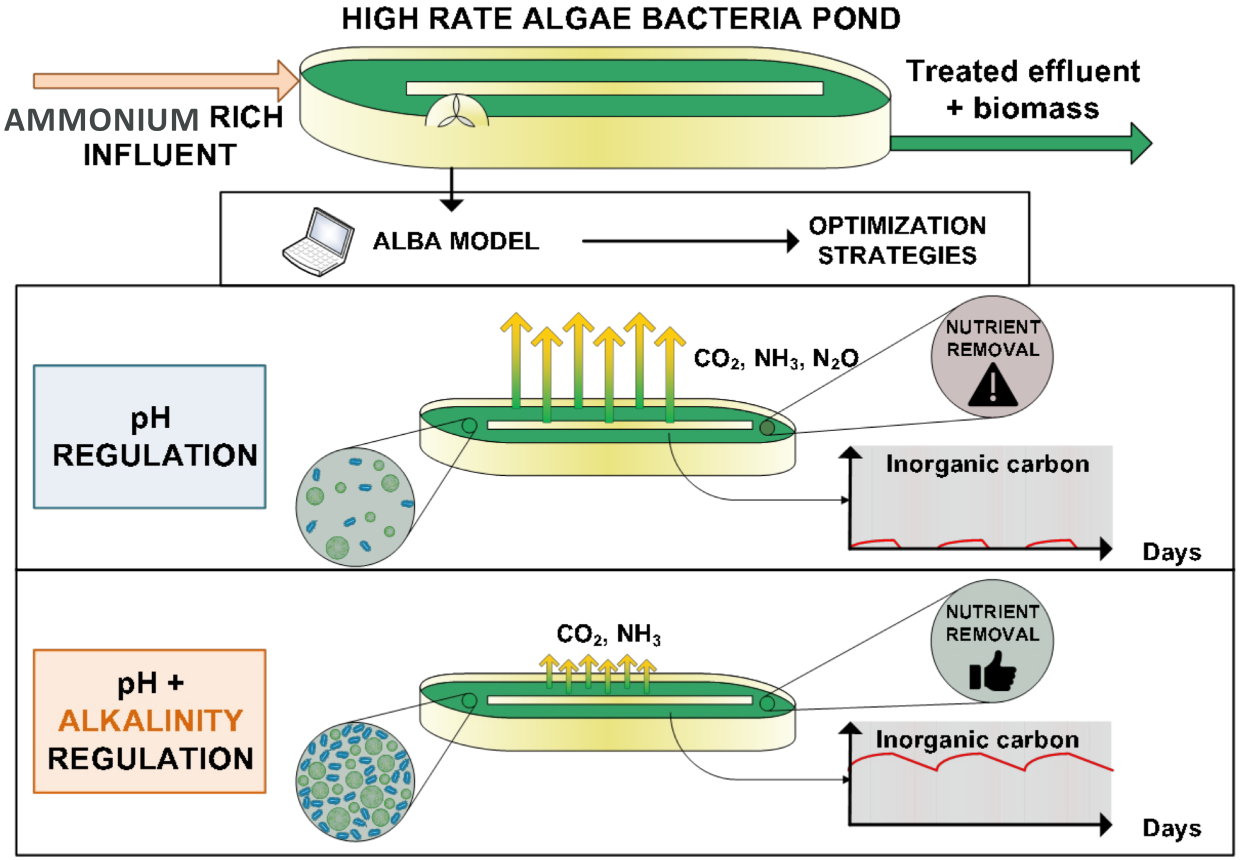
R^2=0.93



Inorganic carbon limitation and N_2O production/emissions



INORGANIC CARBON LIMITATION



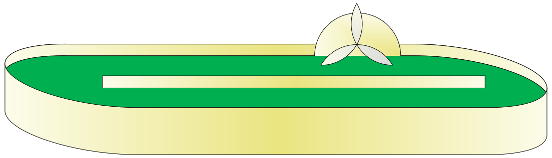
Can algae-bacteria system environmental benefits be compromised by N_2O emissions?

Range of limiting inorganic carbon concentration leading to N_2O production: 2.4 - 12 gC m^{-3} corresponding to 0.17 – 0.87 gC-CO_2 m^{-3}

(Mellbye et al. 2016)

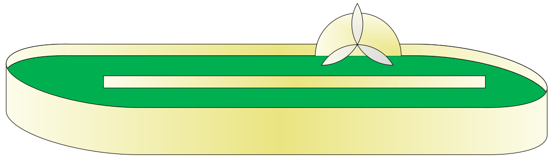
PILOT-SCALE RACEWAYS: MANIPULATING ALKALINITY

R1: GINKO



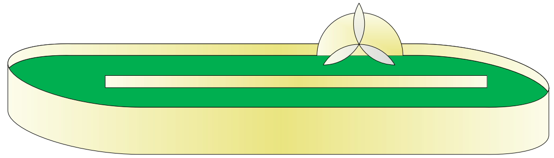
- Diluted and centrifuge digestate
- + P (K_2HPO_4)
- ++ NH_4^+ (NH_4Cl)

R2: LOTUS



- Diluted and centrifuge digestate
- + P (K_2HPO_4)

R3: IRIS



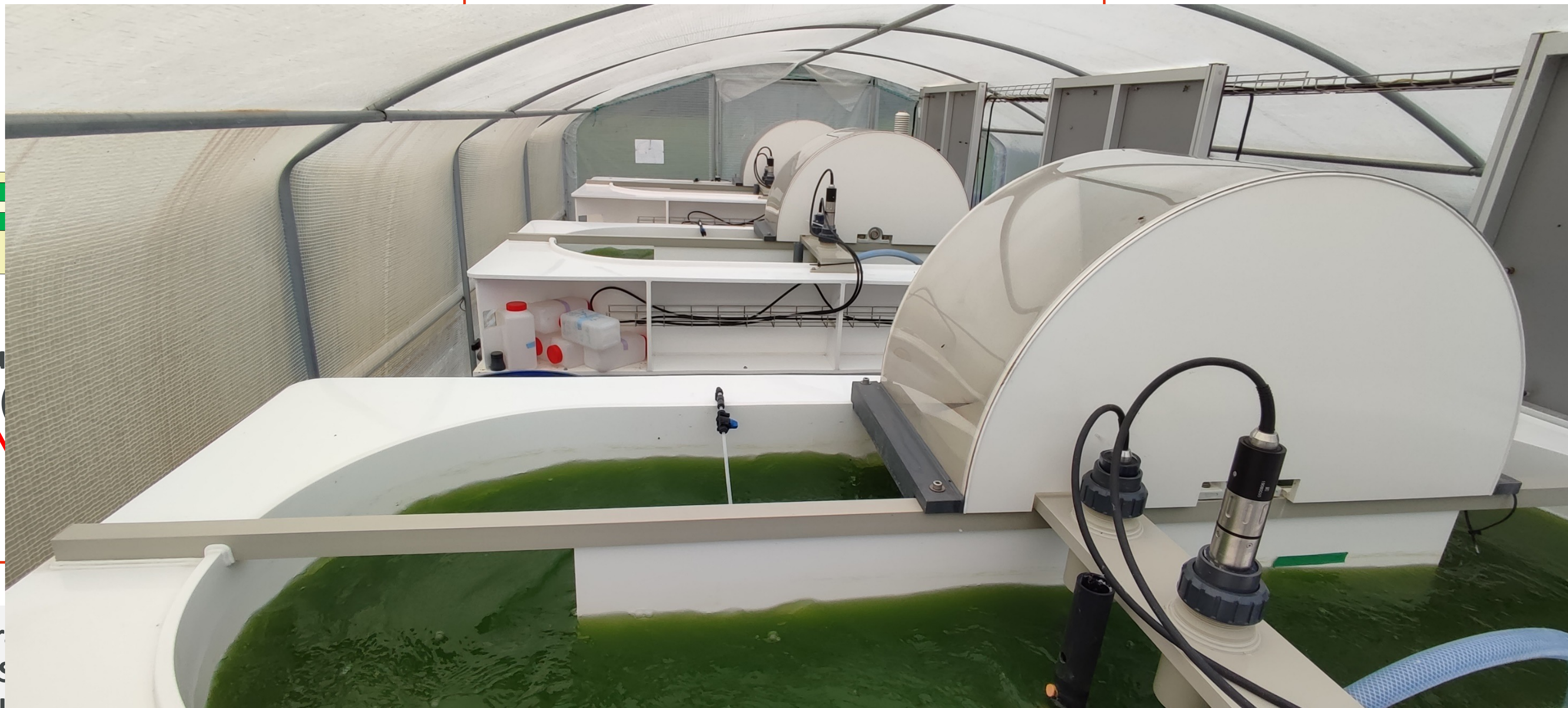
- Diluted and centrifuge digestate
- +P (K_2HPO_4)
- ++ ALK ($NaHCO_3$)
- ++ NH_4^+ (NH_4Cl)

Operational parameters:
- Semi-batch: 7 days
- Liquid depth: 0.25 m
- pH set up: 7.5 - 8.5

Semi-batch regime:
- Influent: 0.5 L digestate diluted in 300 L of tap water
- Reactor: 100 L of mixed liquor

Conditions determined by numerical pre-simulations

PILOT-SCALE RACEWAYS: MANIPULATING ALKALINITY



- Dilu
- + P (
- ++ N

igestate

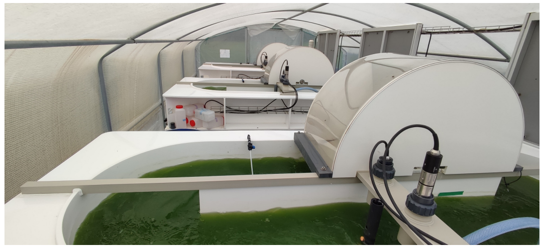
Oper
- S
- Liquid depth: 0.25 m
- pH set up: 7.5 - 8.5

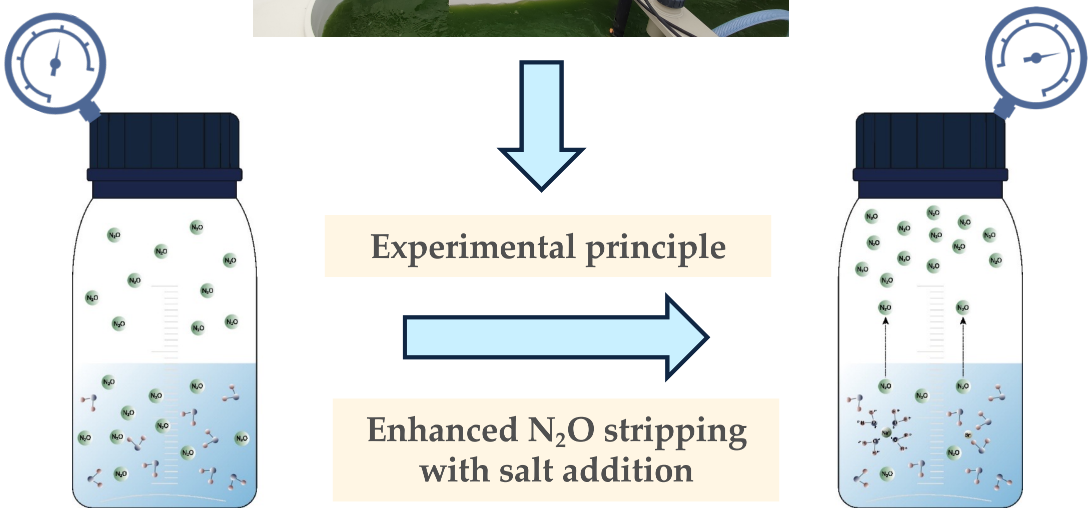
of tap water
- Reactor: 100 L of mixed liquor

ned

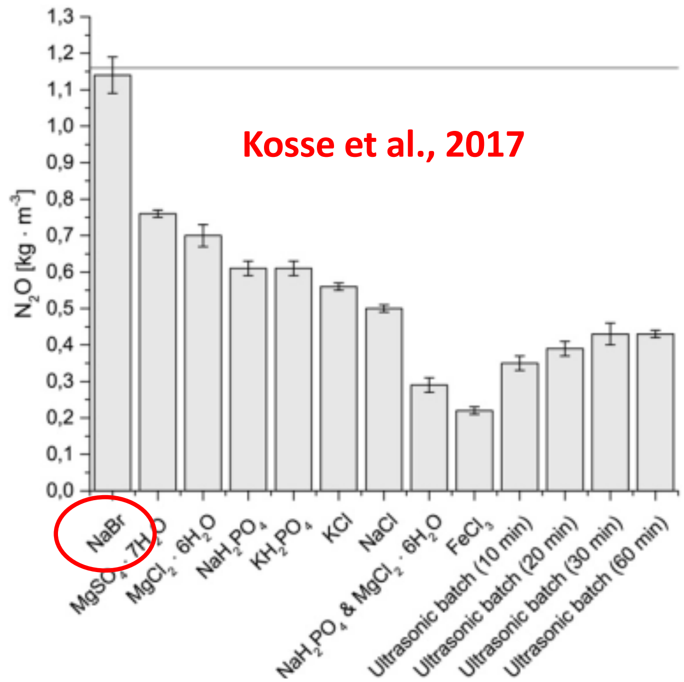
pre-simulations

MEASURING DISSOLVED N_2O: SALTING OUT METHOD



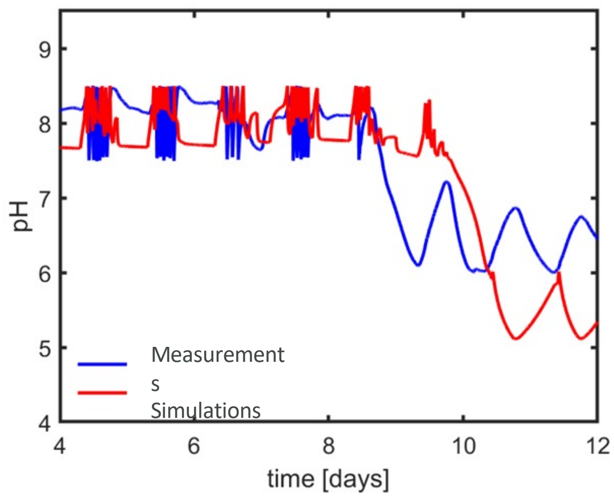


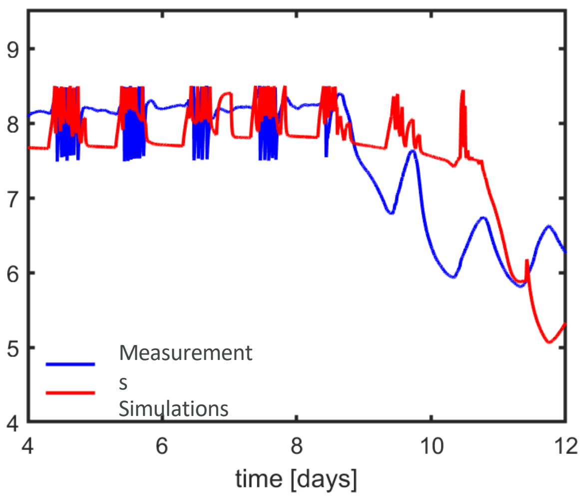
- Gas chromatography analysis of the gas phase
- ECD (Electro Capture Detector), for very low atmospheric concentration
- Working at constant volume and measuring the pressure variation

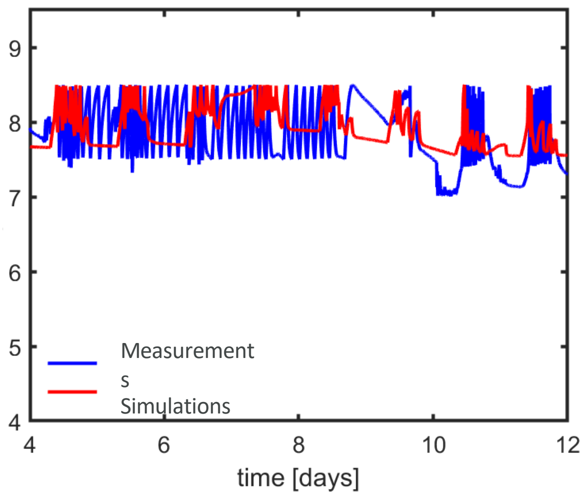


Best salt to use for N_2O stripping: NaBr

RESULTS: pH dynamics

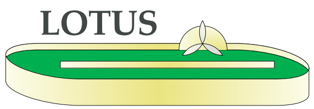


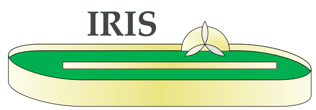




pH is regulated and even drops naturally

++ NH4 (NH_4Cl)

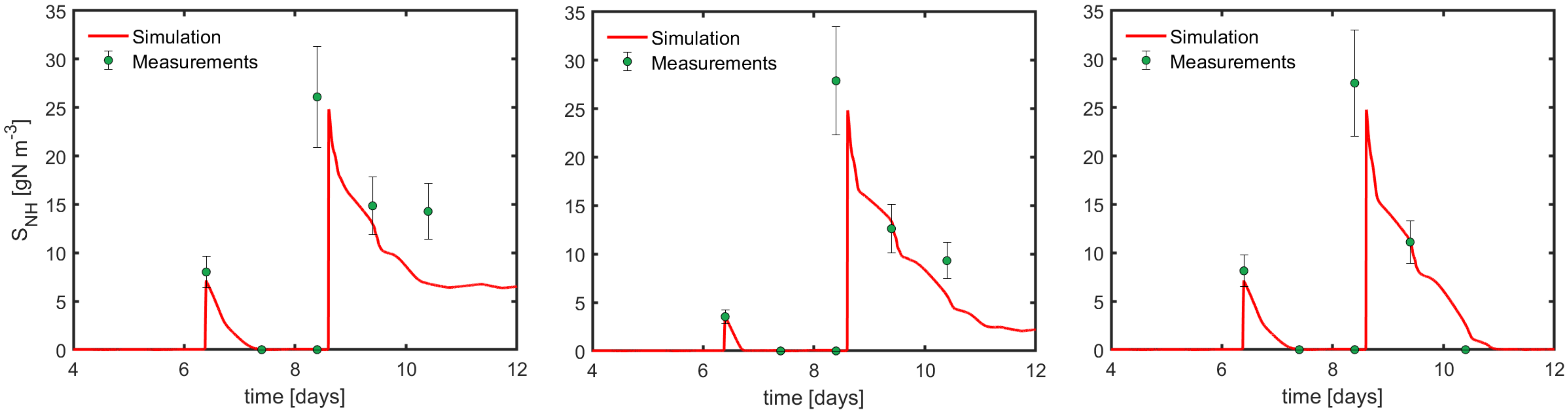




++ ALK ($NaHCO_3$)

++ NH4 (NH_4Cl)

RESULTS: exhaustion of alkalinity

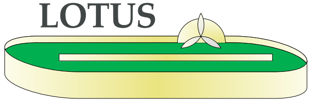


Consumption of NH_4^+ + production of NO_2^- and NO_3^- → loss of alkalinity

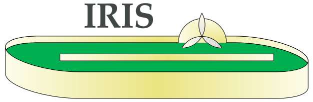
GINKO

++ NH4 (NH_4Cl)

LOTUS



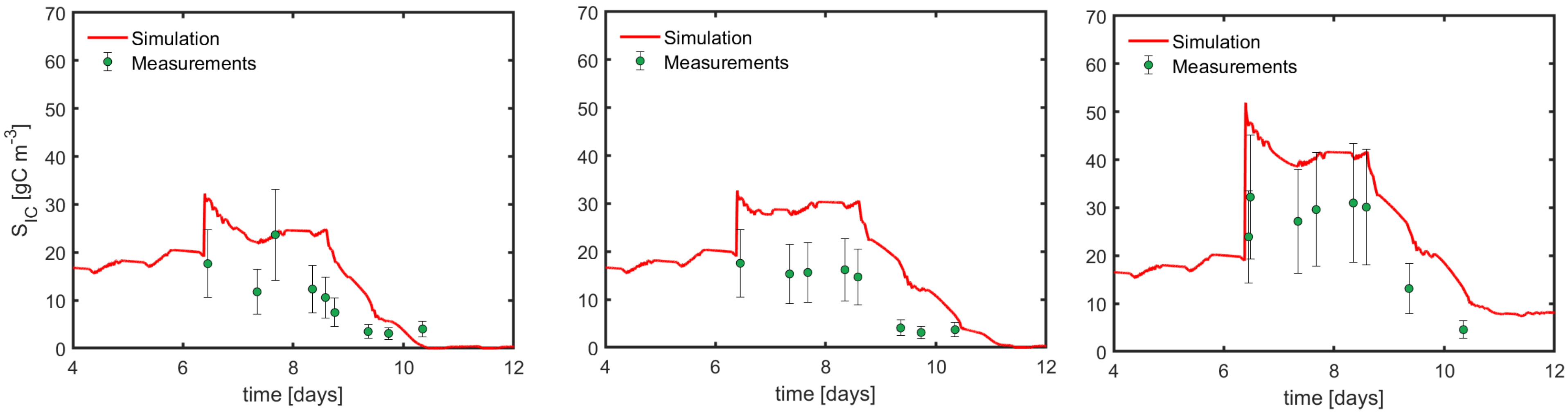
IRIS



++ ALK ($NaHCO_3$)

++ NH4 (NH_4Cl)

RESULTS: Inorganic carbon limitation

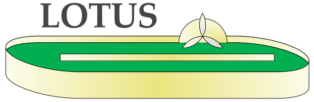


Despite pH regulation < 8.5 , inorganic carbon becomes limiting

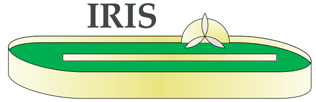
GINKO

++ NH4 (NH_4Cl)

LOTUS



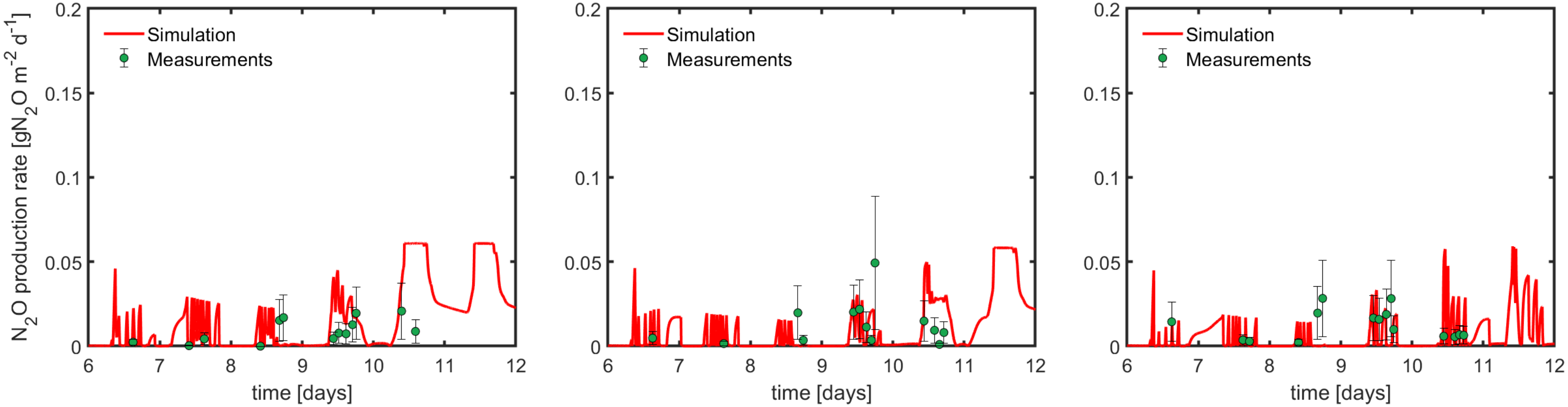
IRIS



++ ALK ($NaHCO_3$)

++ NH4 (NH_4Cl)

RESULTS: N_2O production rate



Frequent N_2O spikes related to pH regulation

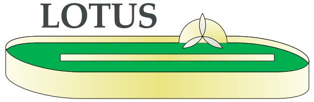
16.5 ± 19.5 mgN_2O m^{-2} d^{-1}

GINKO

++ NH4 (NH_4Cl)

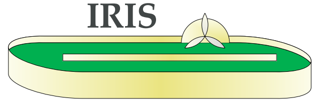
10.6 ± 15.7 mgN_2O m^{-2} d^{-1}

LOTUS



5.9 ± 10.0 mgN_2O m^{-2} d^{-1}

IRIS

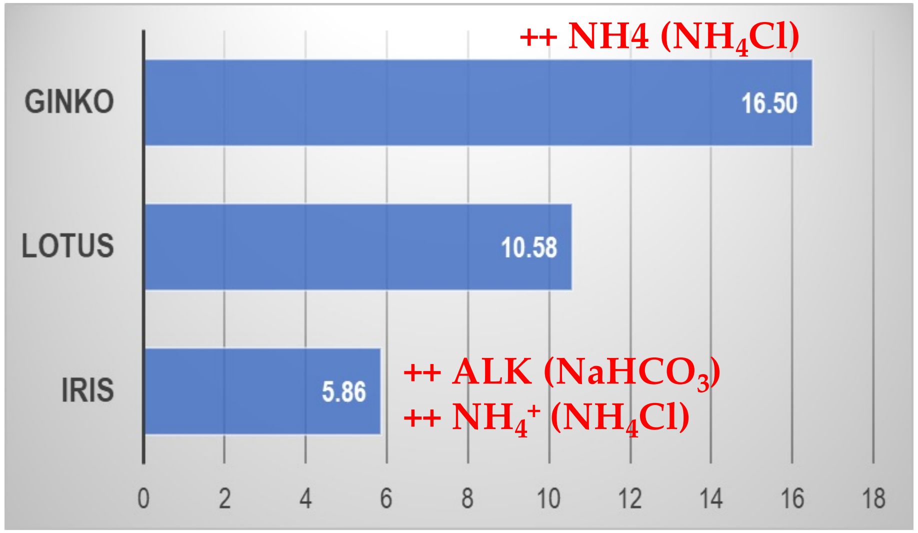


++ ALK ($NaHCO_3$)

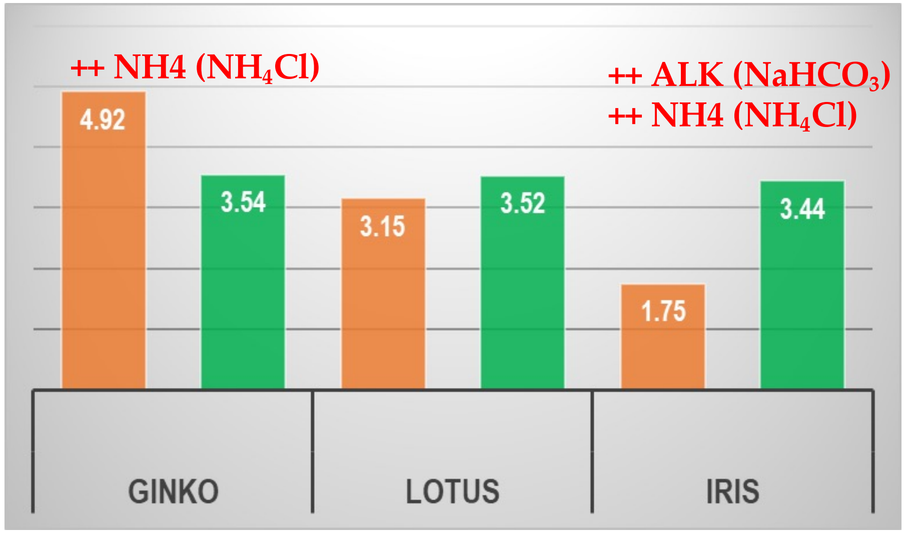
++ NH4 (NH_4Cl)

RESULTS: N_2O PRODUCTION RATE VS CO_2 FIXED

Average N_2O production rate [$mgN_2O\ m^{-2}\ d^{-1}$]

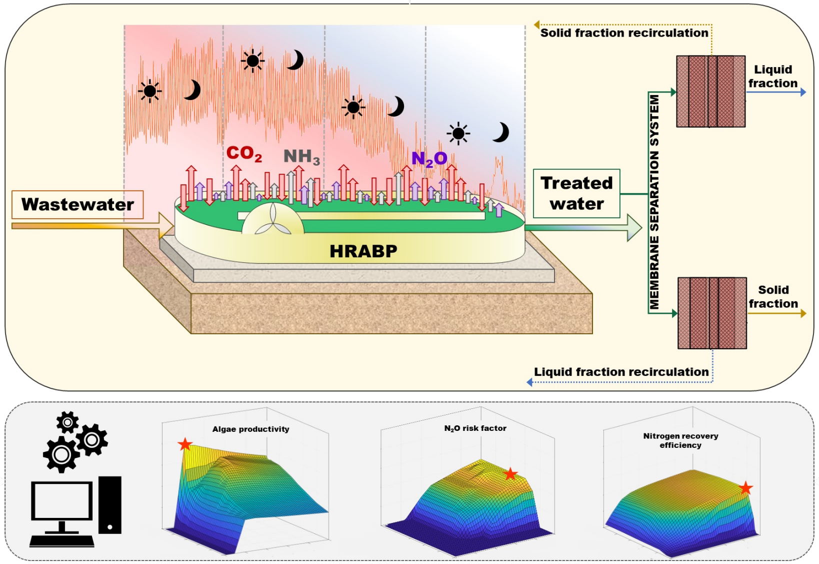


Fixed CO_2 [$gCO_2\ m^{-2}\ d^{-1}$] vs
emitted N_2O [$gCO_{2,EQ}\ m^{-2}\ d^{-1}$]



In the worst case (lowest alkalinity) the N_2O flux (CO_2 eq.) is higher than the fixed CO_2

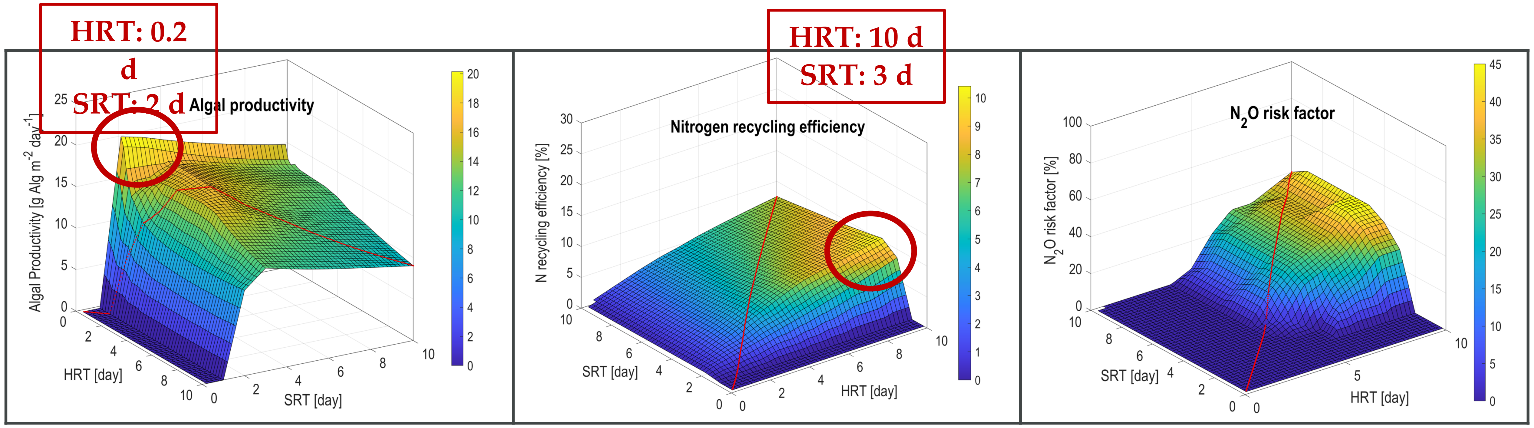
Decoupling HRT - SRT and manipulating alkalinity



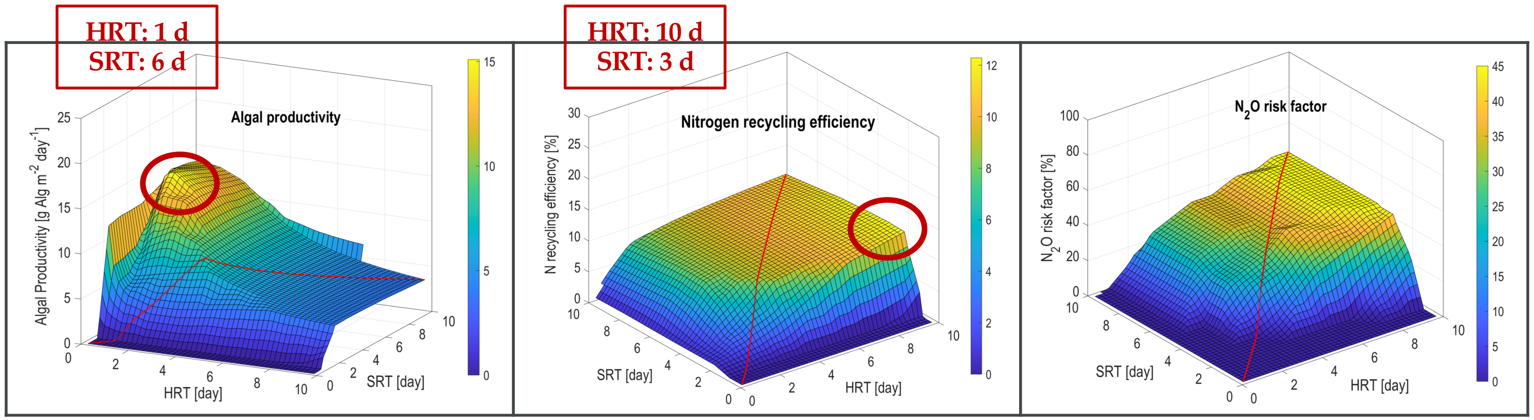
Many degrees of freedom

RESULTS FOR NOMINAL TA AND DIFFERENT LIQUID DEPTHS

- Liquid depth (δ_L) 0.22 m;
- Total Alkalinity (TA) 10 mol m^{-3}

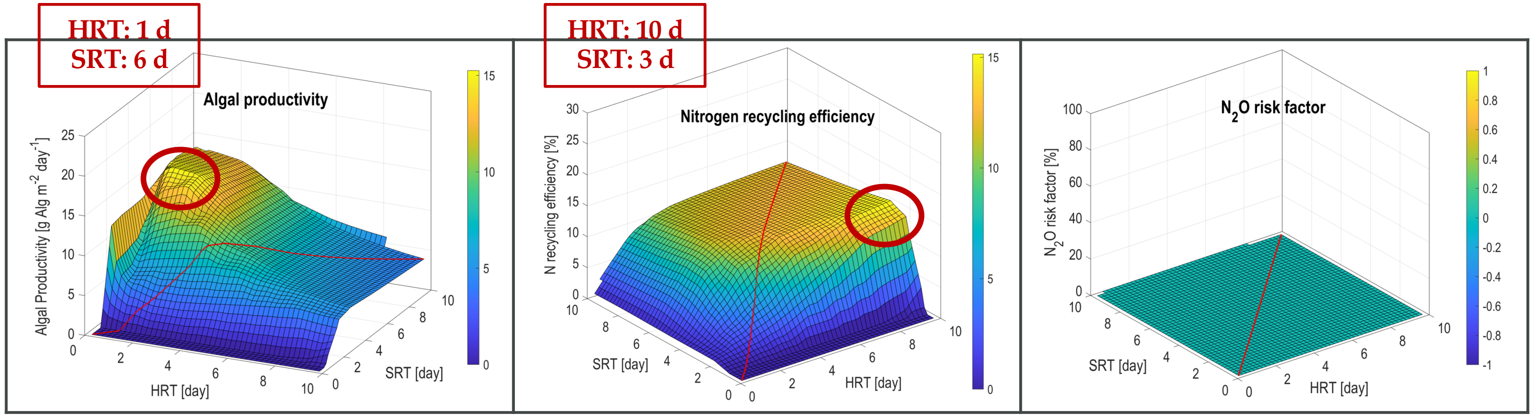


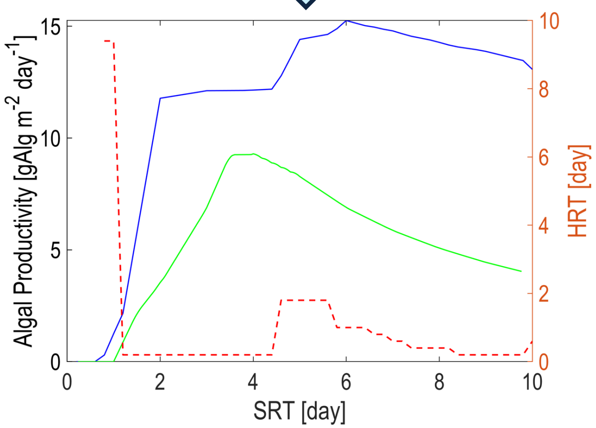
- Liquid depth (δ_L) 0.06 m;
- Total Alkalinity (TA) 10 mol m^{-3}



RESULTS FOR δ_L: 0.06 m and increased TA

- Liquid depth (δ_L) 0.06 m;
- Total Alkalinity (TA) 22 mol m^{-3}





Scenario where the HRT (red dotted line) is adapted according to the SRT for maximizing algal productivity

Scenario with no solid/liquid separation (HRT = SRT)

CONCLUSIONS

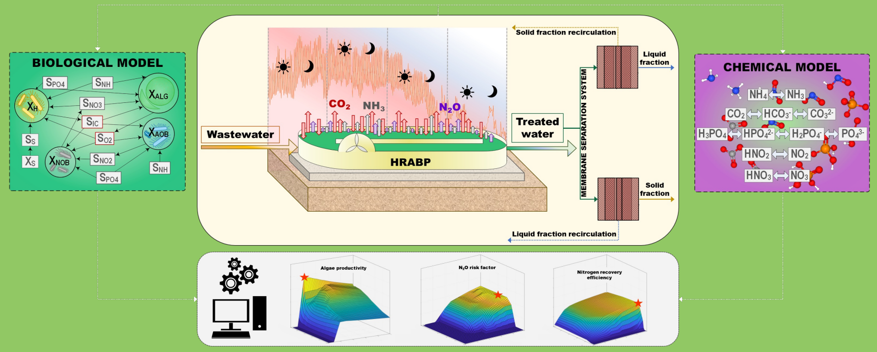
- A general framework for simulating outdoor bioreactors (biology + chemistry + heat transfer)
- ALBA model: a nonlinear model to see in the invisible and identify fluxes
- In the worst case (low alkalinity) the emitted N_2O is larger than the fixed CO_2
- Increasing alkalinity is the solution to enhance the process efficiency and avoid N_2O emission
- Decoupling HRT and SRT turns out to be efficient, when combined with liquid depth adaptation and alkalinity addition.
- The efficiency in nitrogen recovery in the algal biomass and the algal productivity cannot be maximized simultaneously.
- Modelling revealed to be a decisive tool to guide the understanding and the optimization of complex process dynamics.
- Further optimizing the process operations on a daily basis

Inria

Francesca CASAGLI

Bioco2re

Thank you for your attention!



IWA Specialist Group on Modelling and Integrated Assessment Webinar:
"Modelling of phototrophic systems for resource recovery from wastewater"

21/12/2022

IWA

APPENDIX

CHEMICAL MODEL

$$NH_3,\ NH_4^+,\ NO_2^-,\ HNO_2,\ NO_3^-,\ HNO_3,\ CO_2,\ HCO_3^-,\ CO_3^{2-},\ H_3PO_4,\ H_2PO_4^-,\ HPO_4^{2-},\ PO_4^{3-}, OH^-,\ H^+$$

15 unknown: dissociated forms

States related to the dissociated forms

$$S_{PO_4}, S_{NO_2}, S_{NO_3}, S_{NH}, S_{IC}$$

5 mass balances + 9 dissociations

The charge balance can be written accounting for the dependence of the dissociated fractions from the H^+ ions and from the total amount of compounds

$$\begin{aligned} H^+ \ &+ NH_4^+(H^+, S_{NH}) + \Delta_{CAT,AN} - OH^-(H^+) \\ &- NO_2^-(H^+, S_{NO_2}) - NO_3^-(H^+, S_{NO_3}) - HCO_3^-(H^+, S_{IC}) \\ &- 2CO_3^{2-}(H^+, S_{IC}) - H_2PO_4^-(H^+, S_{PO_4}) \\ &- 2HPO_4^{2-}(H^+, S_{PO_4}) - 3PO_4^{3-}(H^+, S_{PO_4}) \ = 0 \end{aligned}$$

$$H^+ = \Phi_{\rm pH}(H^+, S_{PO_4}, S_{NO_2}, S_{NO_3}, S_{NH}, S_{IC})$$

Physical root → algebraic solver, or..

.. computing an estimation of H^+

$$\frac{d\hat{H}^+}{dt} = \hat{K}\left(\Phi_{\rm pH}(\hat{H}^+, S_{PO_4}, S_{NO_2}, S_{NO_3}, S_{NH}, S_{IC}) - \hat{H}^+\right)$$

$\widehat{K}$ = constant tuning the rate for solving the pH equation. For each equilibrium, $\widehat{H}^+$ automatically satisfies the ODE. At the time scale defined by $\frac{1}{\widehat{K}}$, the other states can be considered as constant.

Fast-slow system

KINETICS PRE-CALIBRATION

Integrated light function

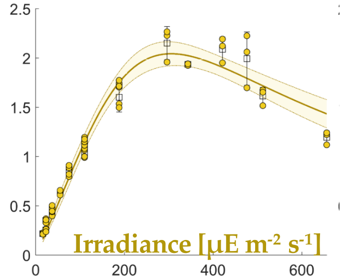
$$\bar{\mu}(I_0,h) = \frac{1}{h}\int_0^h \mu(I(I_0,z))dz$$

1) **Lambert-Beer law** for light extinction

$$I(I_0, z, X_{ALG}) = I_0 e^{-\epsilon X_{ALG} z}$$

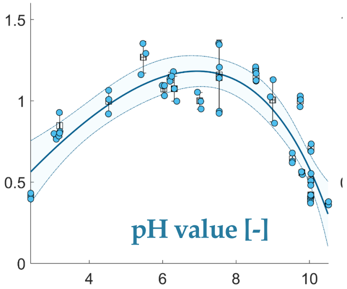
2) **Haldane function** for light dependence: it accounts for both light limitation and photoinhibition phenomena

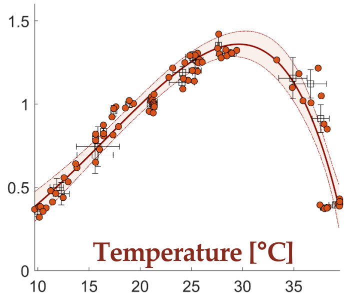
$$\mu(I) = \mu_{max}\frac{I}{I + \frac{\mu_{max}}{\alpha}\left(\frac{I}{I_{opt}} - 1\right)^2}$$



Rosso function for biological pH dependence

$$f_{pH} = \frac{(pH - pH_{max}) \cdot (pH - pH_{min})}{(pH - pH_{min}) \cdot (pH - pH_{max}) - (pH - pH_{opt})^2}$$



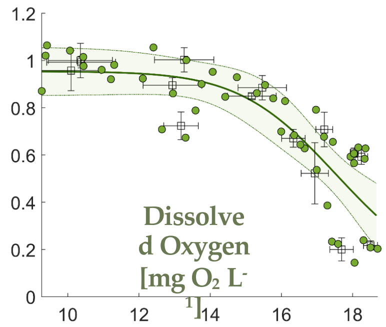


Rosso function for biological temperature dependence

$$f_{T,1} = \frac{(T - T_{max}) \cdot (T - T_{min})^2}{(T_{opt} - T_{min}) \cdot [(T_{opt} - T_{min}) \cdot (T - T_{opt}) - (T_{opt} - T_{max}) \cdot (T_{opt} + T_{min} - 2T)]}$$

Hill type model for biological oxygen ihibition

$$f_{DO} = \frac{K_{DO}^n}{S_{O_2}^n + K_{DO}^n}$$



UNCERTAINTY ANALYSIS

Definition of **absolute-relative sensitivity functions**

$$\tilde{\partial}^{a,r}_{y_i,p_j} = \frac{\partial y_i}{\partial p_j}$$

Construction of the **sensitivity matrix**

$$\Delta_{Y_p} = \left[\frac{\partial y}{\partial p_1}, \ldots, \frac{\partial y}{\partial p_j}\right]$$

Construction of the **Fisher information matrix**

$$F = \sum_{k=1}^{K} \Delta^{T}_{Y_{p,k}} C^{-1} \Delta_{Y_{p,k}}$$

Calculation of **parameters' variance**

$$\delta_{p_j}^{2} = (F^{-1})_{j,j}$$

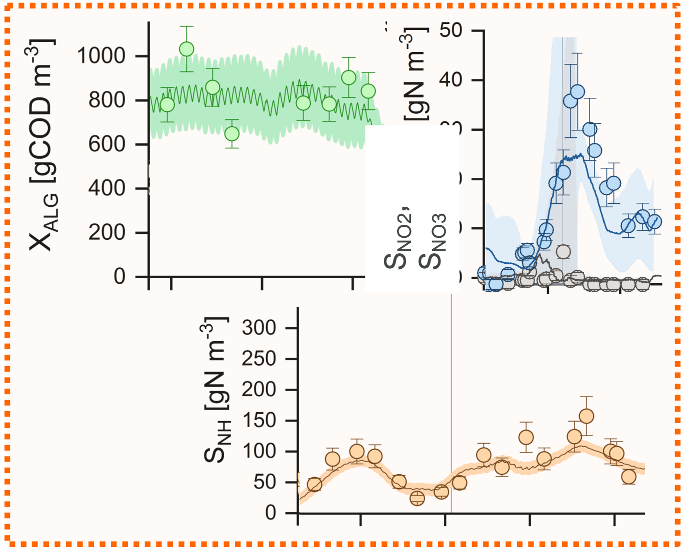
Assessment of linear **error propagations**

$$\sigma_{y_i}(t) = \sqrt{\sum_{j=1}^{m} \left(\frac{\partial y_i}{\partial p_j}(t)\right)^2 \delta^2_{p_j}}$$

Identification of **95% confidence intervals** on model predictions

$$\left[y_i - 1.96\,\sigma_{y_i} \quad y_i + 1.96\,\sigma_{y_i}\right]$$

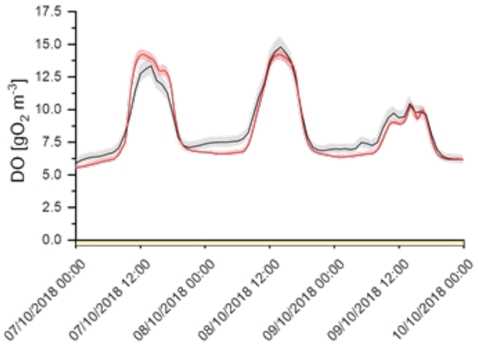
y_i = TSS, COD_S, X_{ALG}, S_{NH}, S_{NO2}, S_{NO3}, S_{O2} and pH



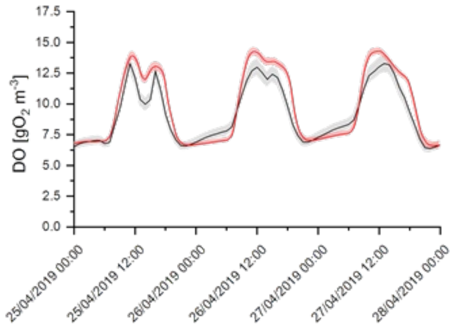
SIMULATION RESULTS: SHORT-TERM

DO

Calibration

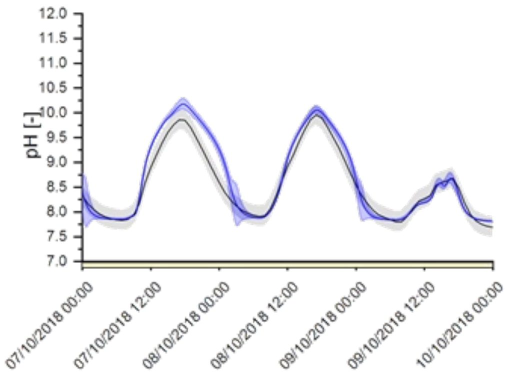


Validation

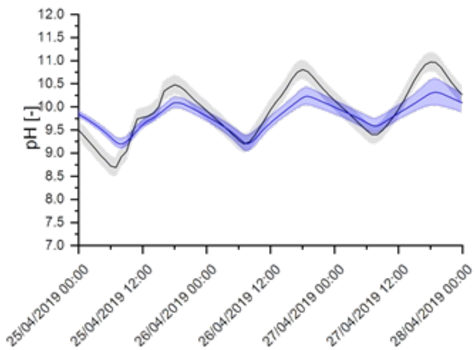


pH

Calibration

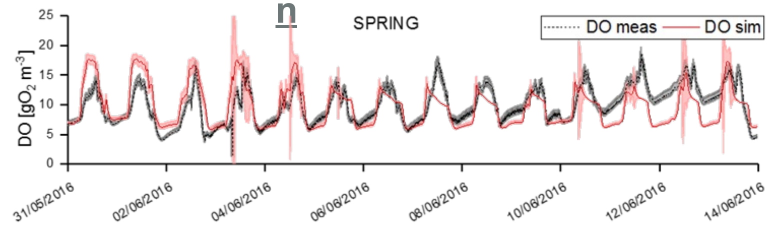


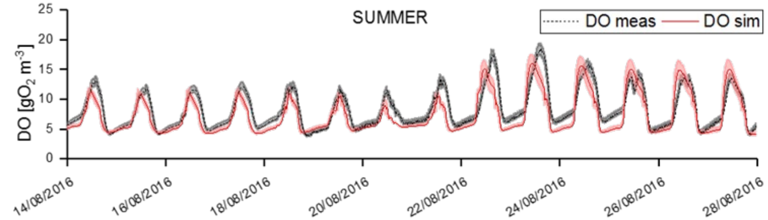
Validation

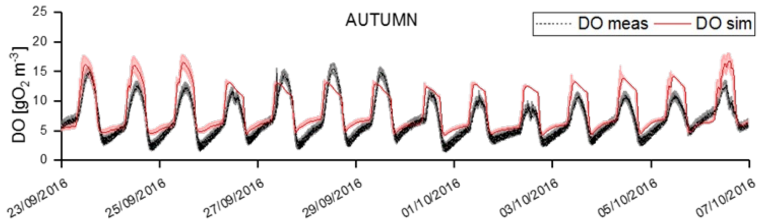


DO

Validatio
n

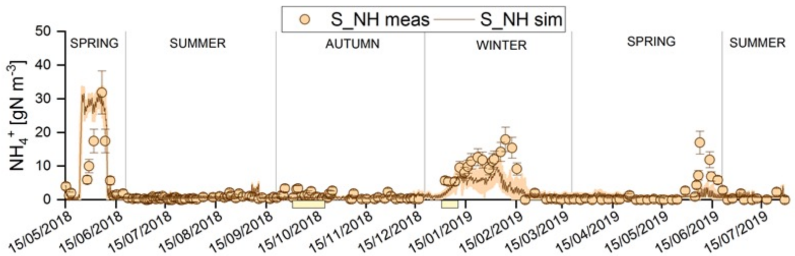


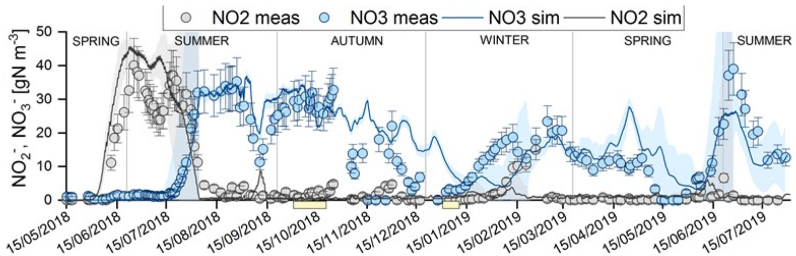


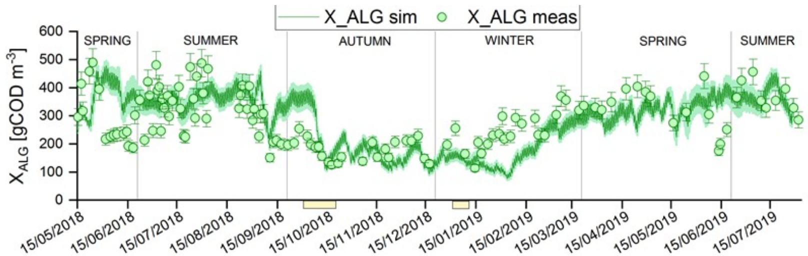


SIMULATION RESULTS: LONG -TERM (1/2)

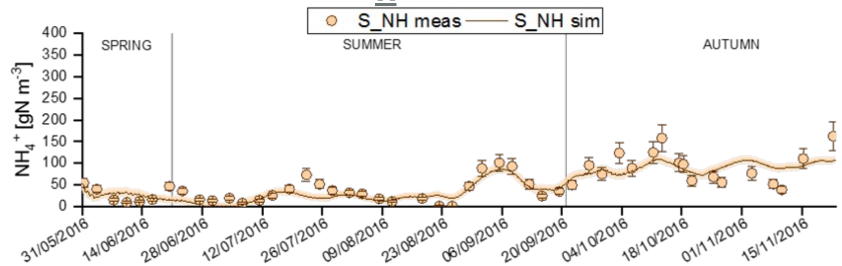
Calibration - Validation

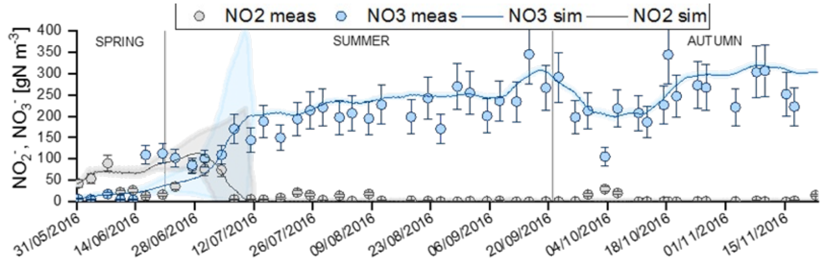


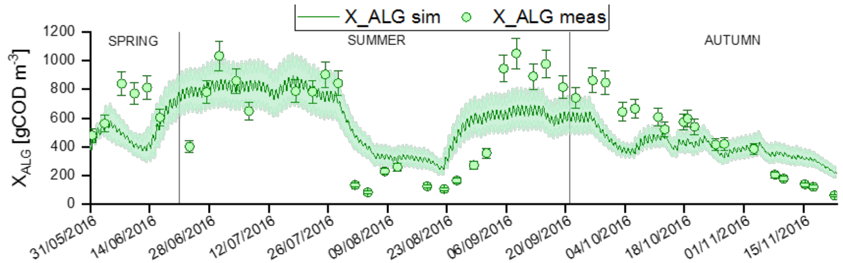




Validatio
n

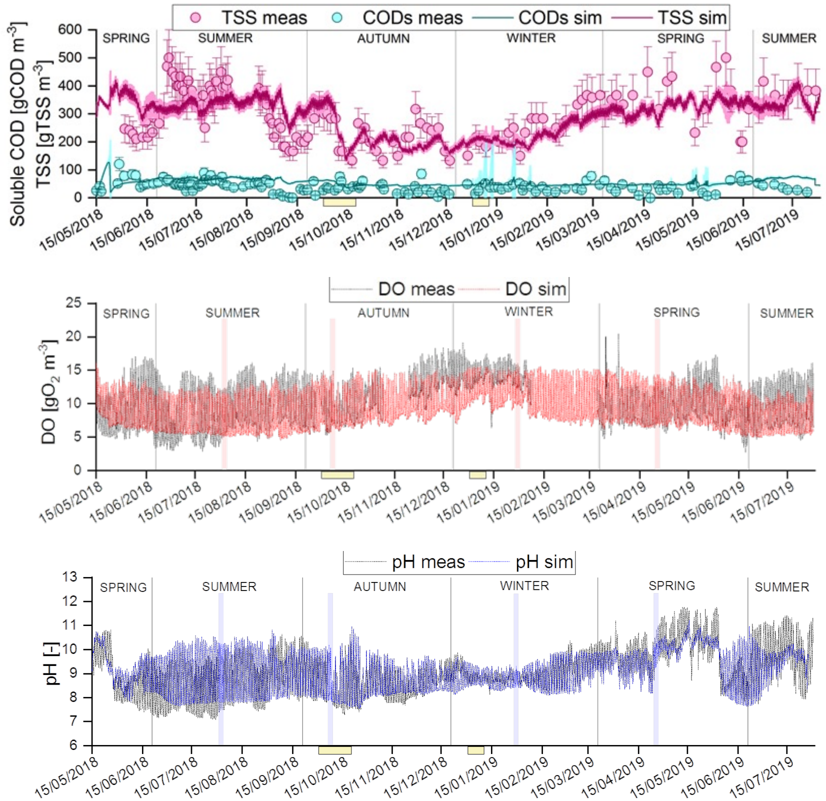




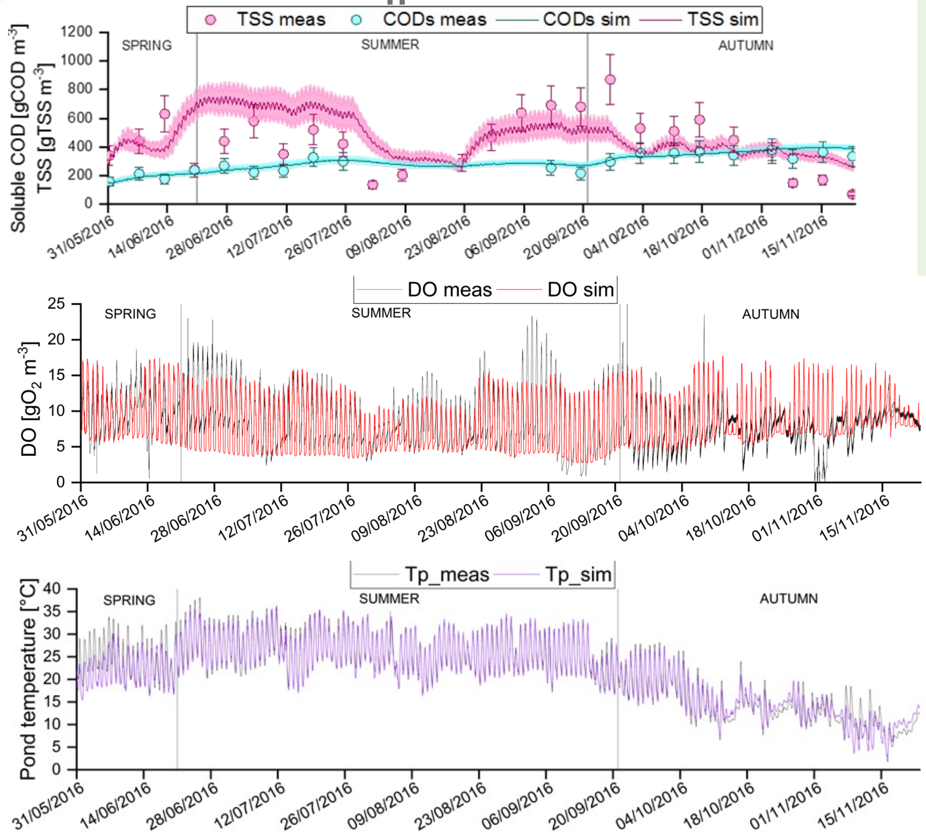


SIMULATION RESULTS: LONG-TERM (2/2)

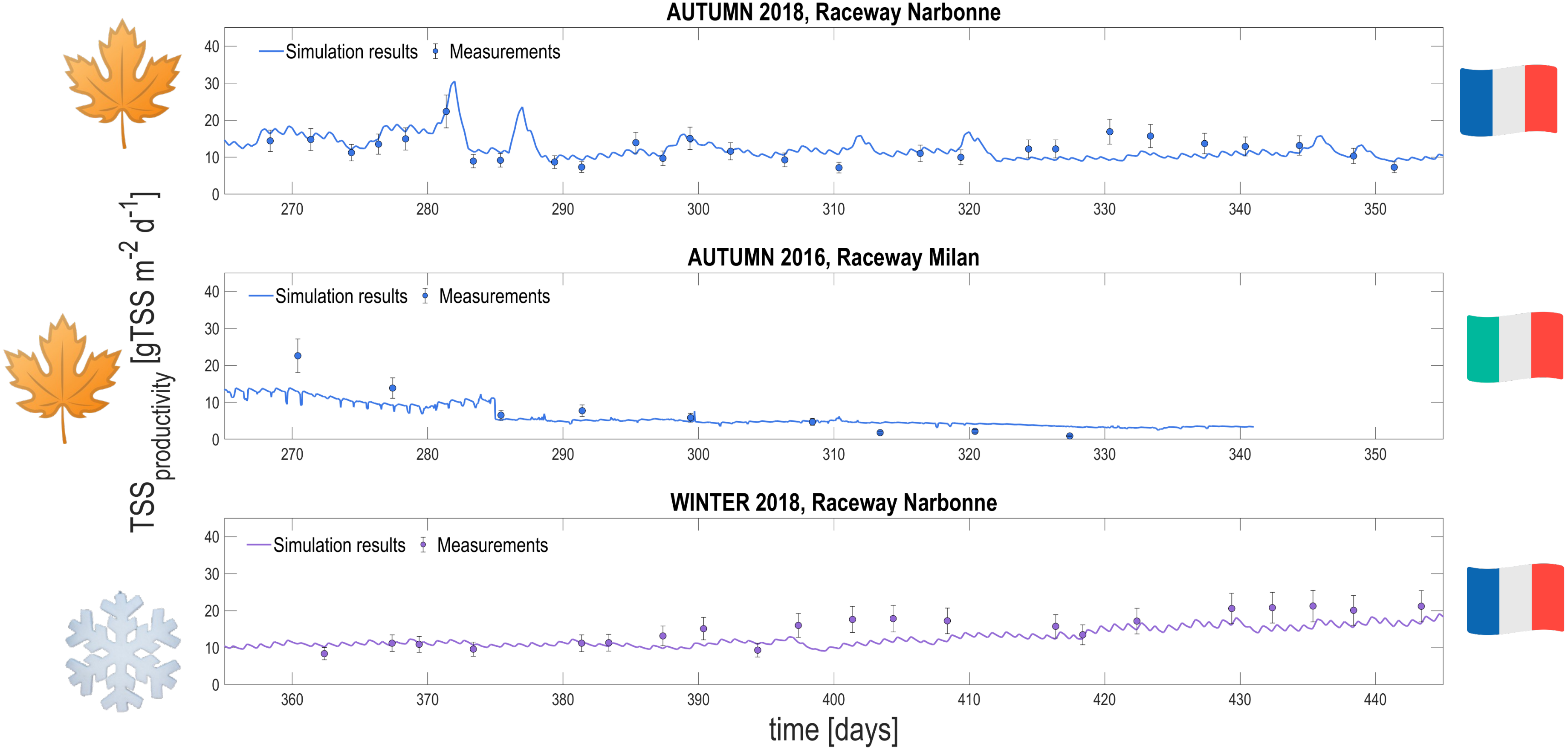
Calibration - Validation



Validation

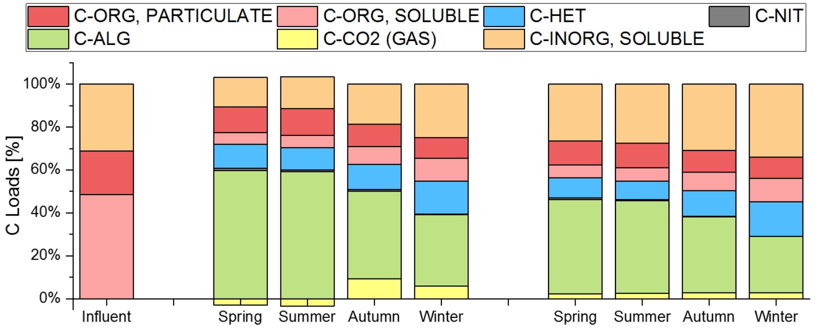


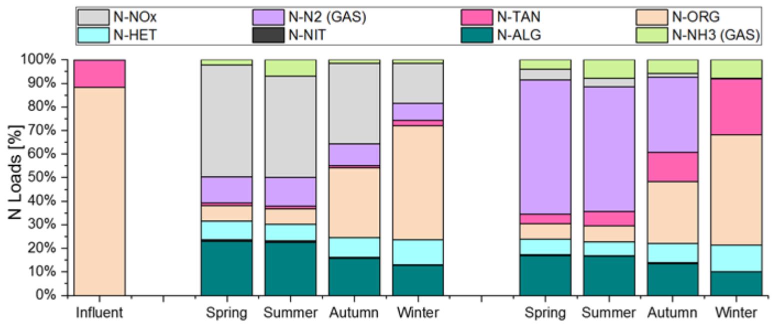
TSS PRODUCTIVITY VALIDATION



CARBON AND NITROGEN FLUXES UNDER DIFFERENT k_La

MUNICIPAL WASTEWATER, NO pH CONTROL, HRT: 5 d





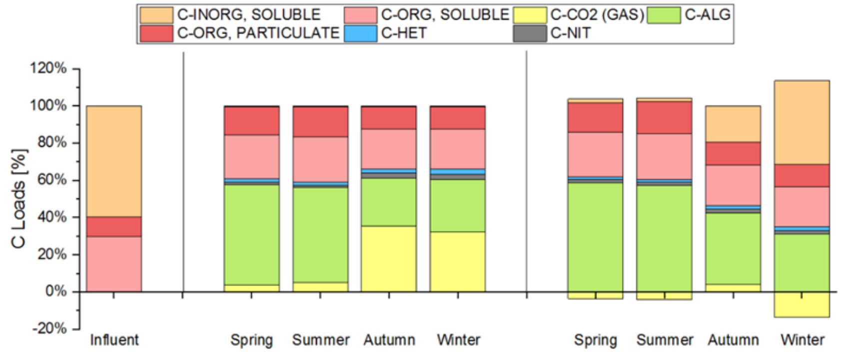
kLa = 34 d-1

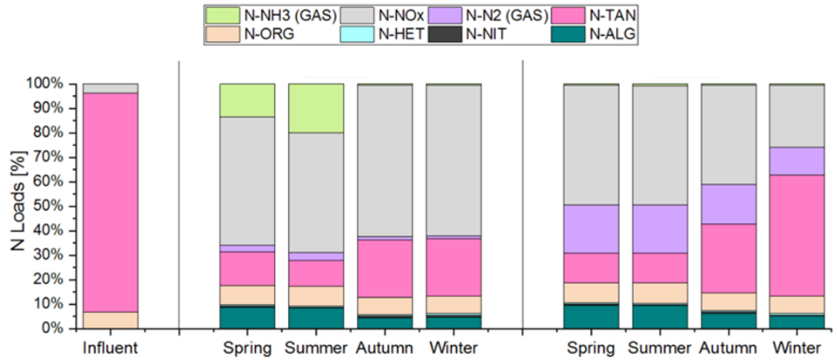
kLa = 0.5 d-1

C fluxes

N fluxes

DIGESTATE, pH CONTROL: 7.5, HRT: 10 d





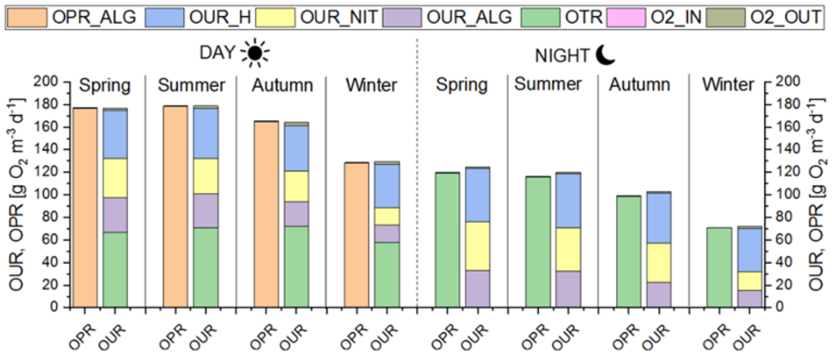
kLa = 34 d-1

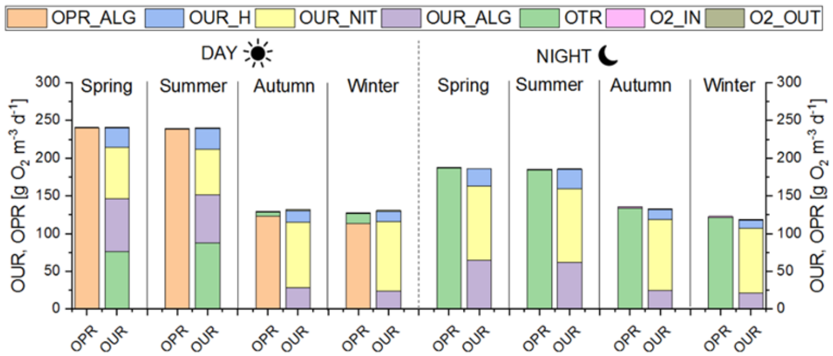
kLa = 0.5 d-1

DEEP INSIGHT INTO OXYGEN BALANCE

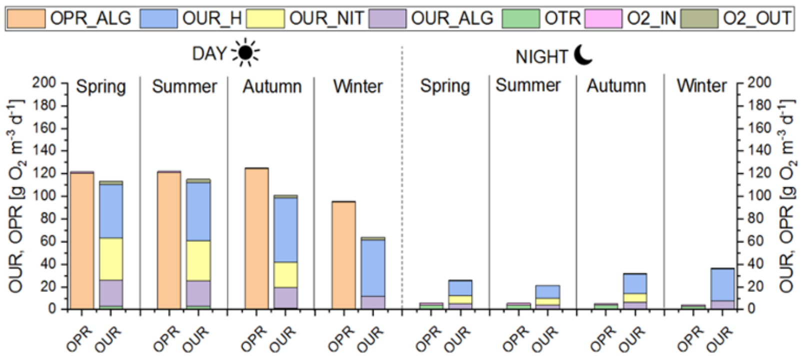
MUNICIPAL WASTEWATER, NO pH CONTROL, HRT: 5 d

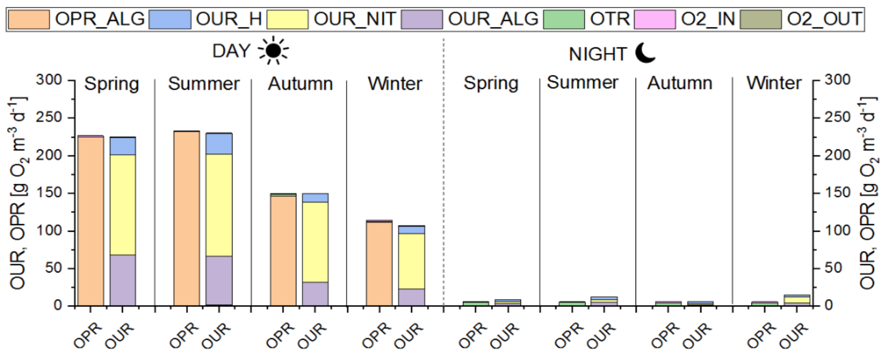
DIGESTATE, pH CONTROL: 7.5, HRT: 10 d





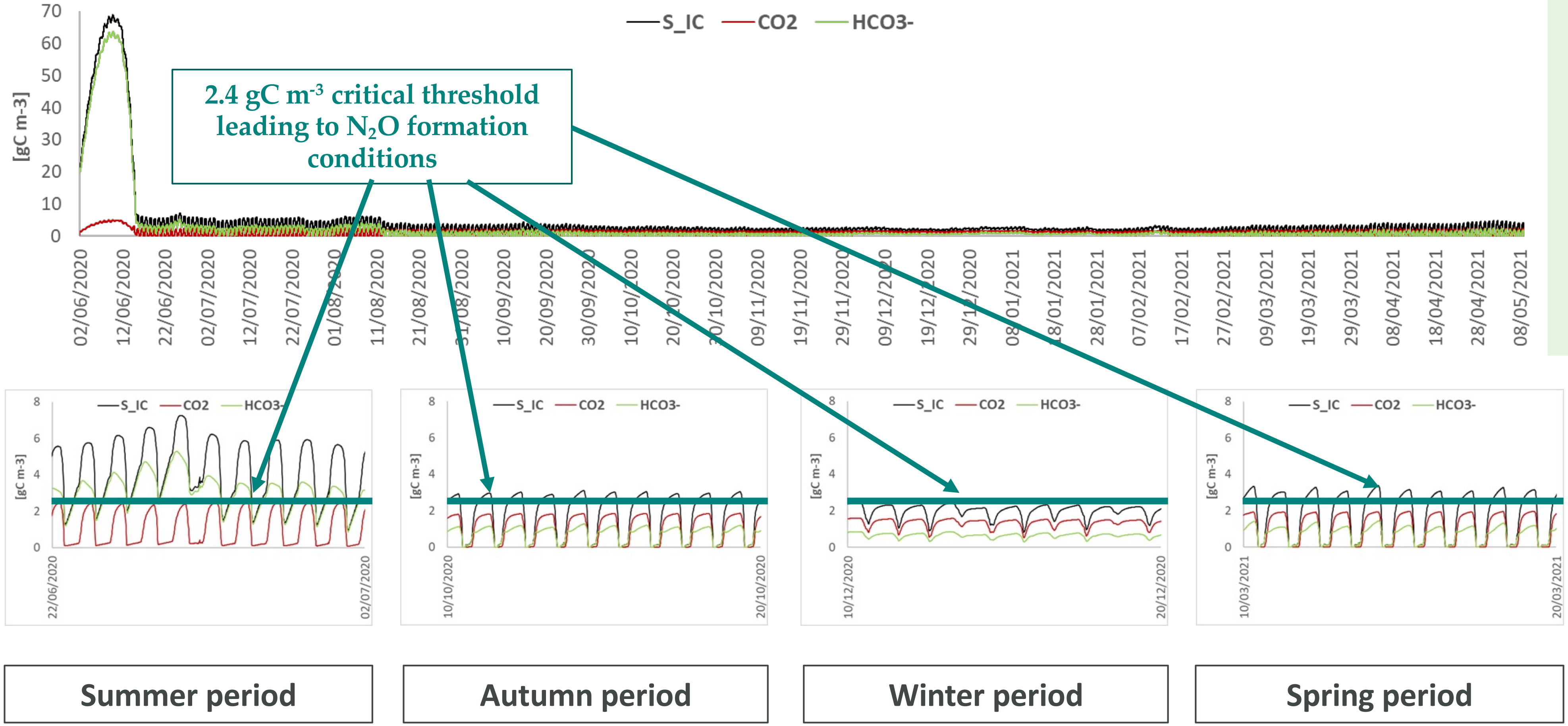
kLa = 34 d^{-1}





kLa = 0.5 d^{-1}

SIMULATIONS: INORGANIC CARBON LIMITATION



AGENDA AND HOUSEKEEPING

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Q&A Session Moderator: *Elena Ficara (Politecnico di Milano, Italy)*

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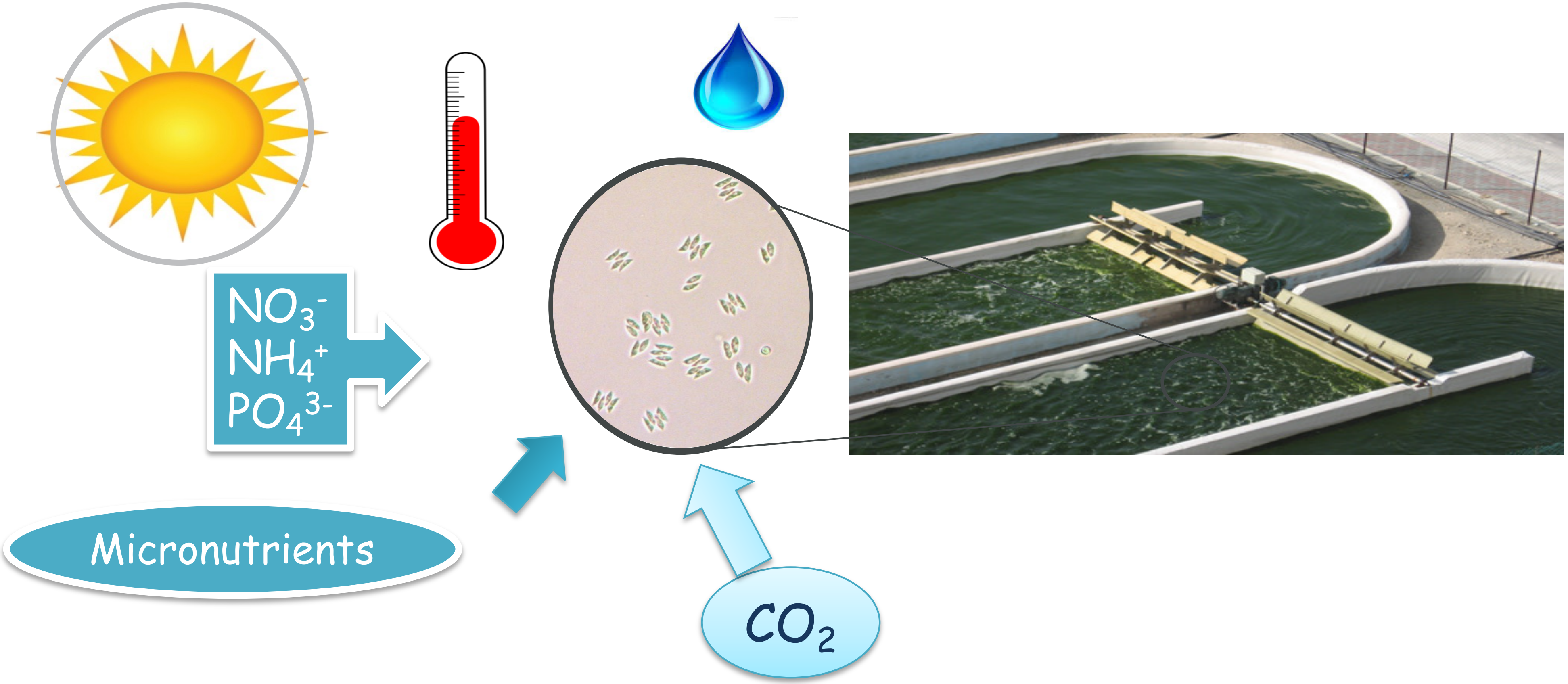
Modeling light distribution in photobioreactors and its impact on algal growth

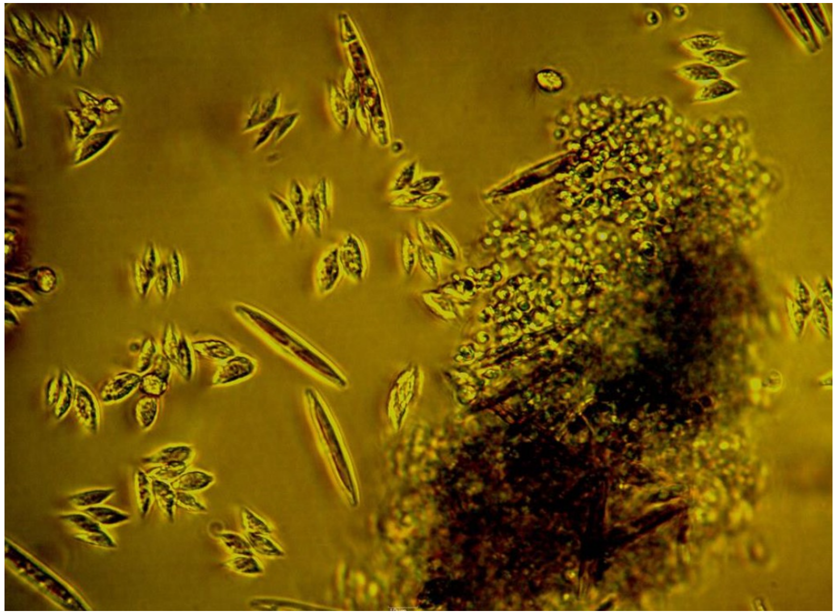
Borja Valverde-Pérez, DTU Sustain
(bvape@dtu.dk)

Requirements for algal growth



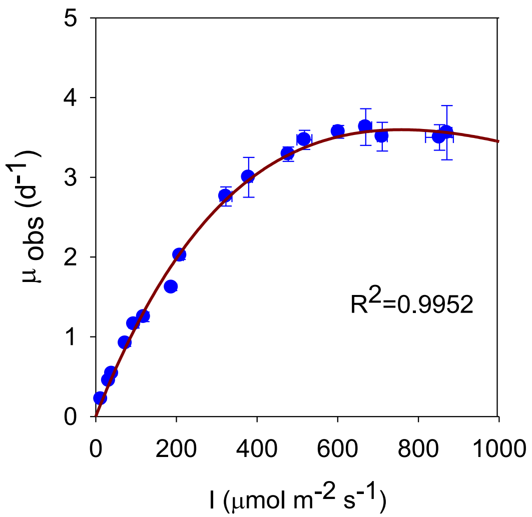
Agenda

- Impact of light on algal growth
- Factors affecting light attenuation in photobioreactors
- Modeling approaches



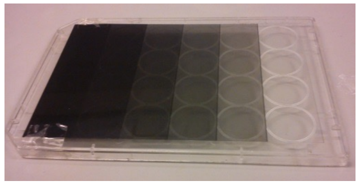
Impact of light on algal growth

Assessing the specific growth rate under different light intensities



Steele equation:

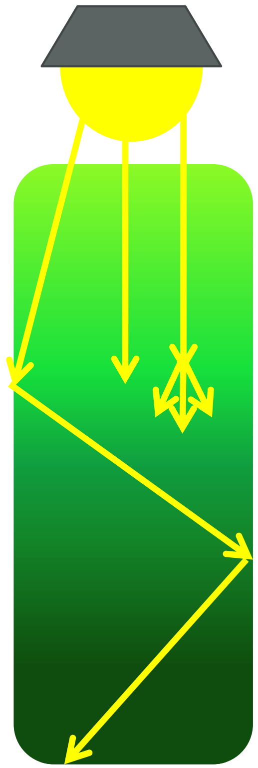
$$\mu = \frac{\mu_{max} * I}{I_s} exp^{1-I/I_s}$$



Wágner et al. 2016

Factors affecting light attenuation in photobioreactors

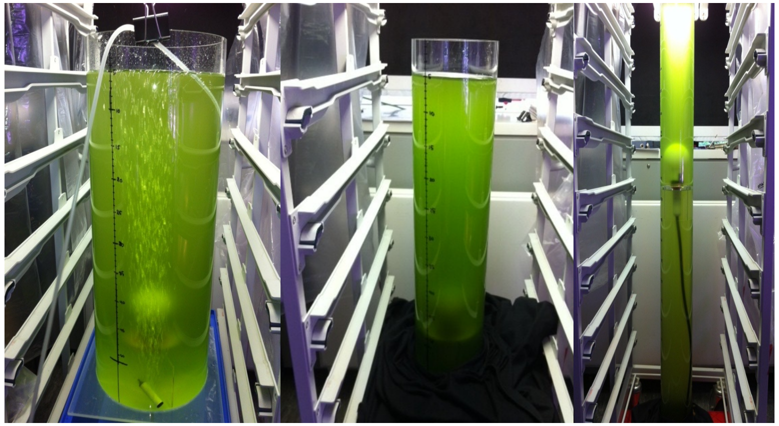
- Adsorption
- Scattering
  - Reflection on reactor wall
  - Scattering on cells
- Self-shading
- Pigmentation
  - Chlorophyll
  - Carotenoids



Factors affecting light attenuation in photobioreactors

<u>Experimental design</u>

- Three different reactor diameters
- Different biomass concentrations
- Different nutrient availability
- Different cultivation media



Wágner et al. 2018

Factors affecting light attenuation in photobioreactors

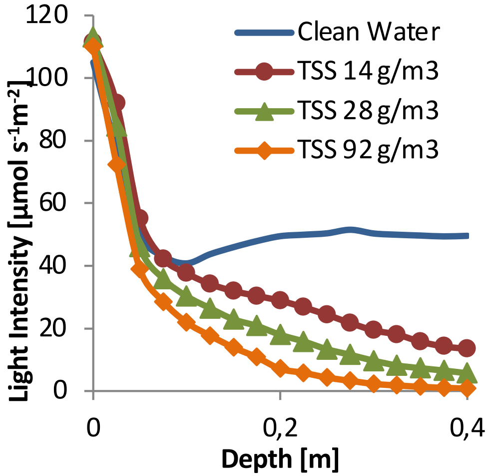
Nutrient availability, biomass concentration and cultivation media affects light distribution

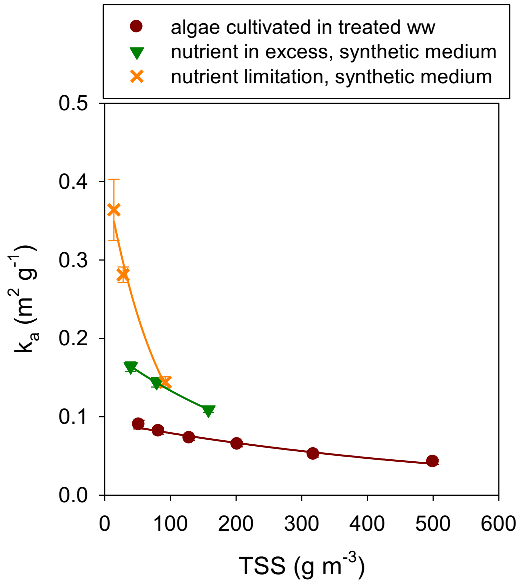
Effect of light scattering

- Under nutrient limited conditions in all three reactors
- Under nutrient in excess conditions with narrow reactor diameter

Lambert-Beer law:

$$I = I_0 * e^{-k_a * X_{Alg} * Z}$$

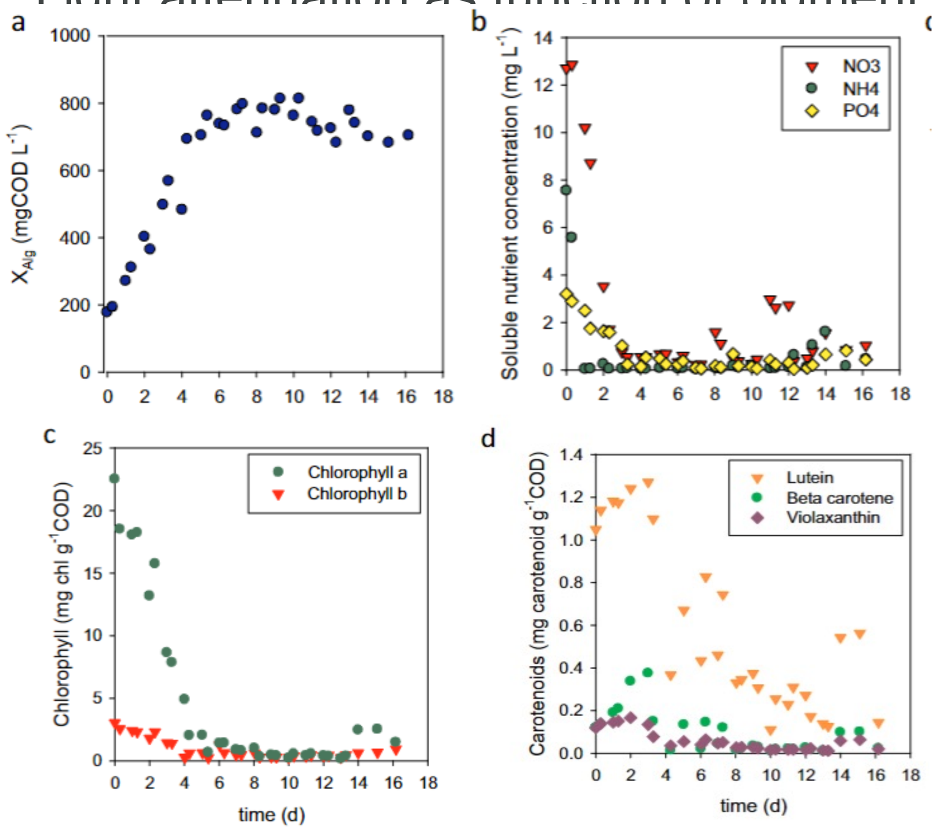


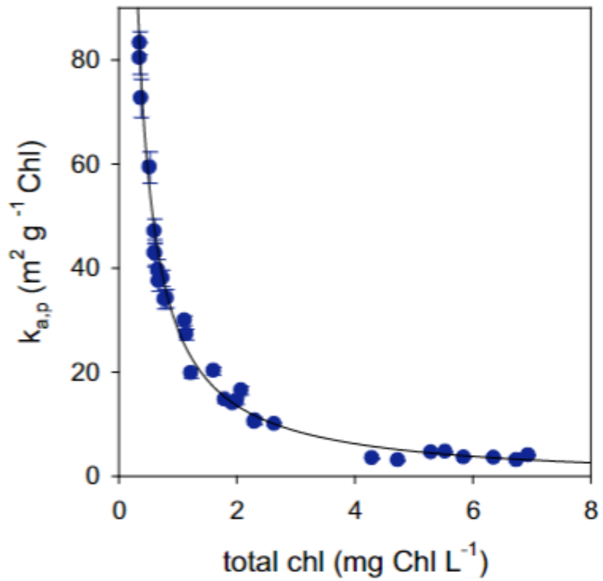


$$k_a = a * e^{-b * X_{Alg}}$$

Factors affecting light attenuation in photobioreactors

Light attenuation as function of pigment concentration

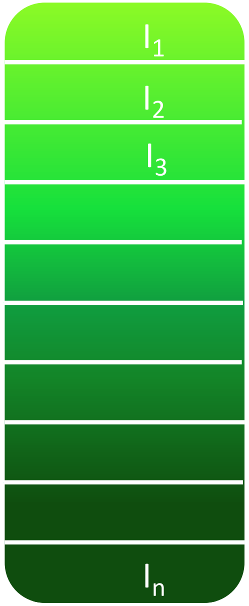




$$k_{a,p} = \frac{a}{X_{Chl}} - b$$

Modeling approaches

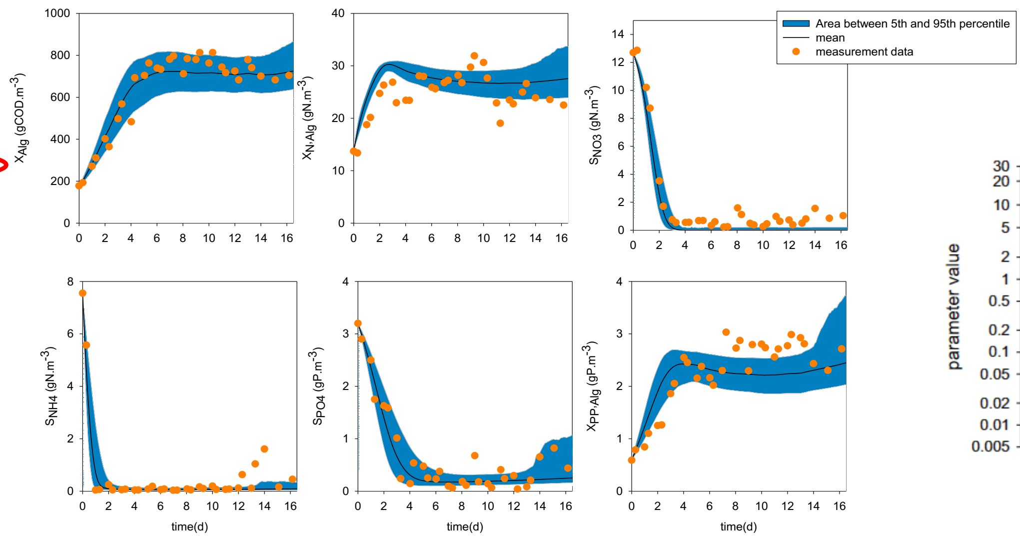
- Average light intensity – over the whole cultivation period
- Variable average light intensity – average light intensity calculated for each time step
- Layer model – light intensity calculated in each layer for each time step

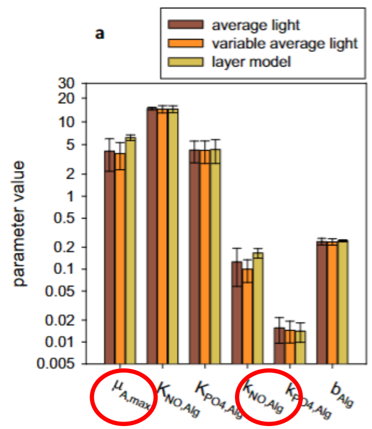


Modeling approaches

	Average light	Variable average light	Layer model
RMSNE (-)			
X_{Alg}	0.194	0.171	0.092
X_{AlgN}	0.131	0.152	0.171
S_{NO3}	0.902	0.898	0.889
X_{AlgP}	0.301	0.264	0.229
S_{PO4}	0.766	0.978	1.036
sum	2.294	2.463	2.417
AIC (-)			
X_{Alg}	290	279	252
X_{AlgN}	75	81	88
S_{NO3}	-2	-1	-3
X_{AlgP}	-27	-28	-45
S_{PO4}	-64	-75	-83
sum	459	465	470
ARILC (-)			
X_{Alg}	0.0047	0.0044	0.0028
X_{AlgN}	0.0025	0.0023	0.002
S_{NO3}	0.031	0.017	0.0085
X_{AlgP}	0.0044	0.0045	0.0033
S_{PO4}	0.023	0.028	0.016
sum	0.065	0.056	0.033

Layer model:





Conclusion

- Microalgal growth rates increase with light intensity until a maximum beyond they suffer photoinhibition
- The light attenuation depends on the pigmentation and the biomass concentration.
- Discretized layer model used to predict the light distribution in PBRs resulted in more accurate prediction of the microalgal biomass concentration.

Water Research 103 (2016) 485–499

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/watres

Towards a consensus-based biokinetic model for green microalgae – The ASM-A

Dorottya S. Wágner[*, 1], Borja Valverde-Pérez[*, 1], Mariann Sæbø, Marta Bregua de la Sotilla, Jonathan Van Wagenen, Barth F. Smets, Benedek Gy. Plósz[*]

Department of Environmental Engineering, Technical University of Denmark, Miljøvej, Building 113, 2800 Kgs. Lyngby, Denmark

Algal Research 35 (2018) 488–499

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/algal

Light attenuation in photobioreactors and algal pigmentation under different growth conditions – Model identification and complexity assessment

Dorottya S. Wágner[a,*,1], Borja Valverde-Pérez[a], Benedek Gy. Plósz[a,b,*]

Thank you!

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Modelling outdoors systems based on Purple Phototrophic Bacteria for resource recovery

Gabriel Capson-Tojo

December 21st, 2022

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INRAE

LBE
Laboratoire Biotechnologie de l'Environnement

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

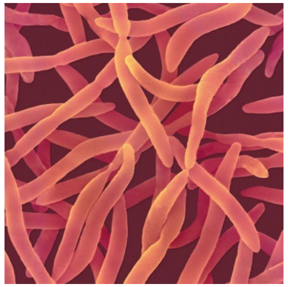
PPB are anoxygenic phototrophs

Anoxygenic photosynthesis

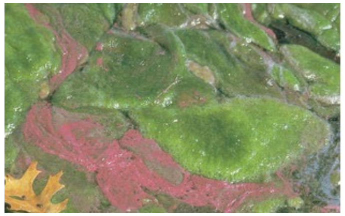
$$CO_2 + 2H_2A + \text{light energy} \rightarrow [CH_2O] + 2A + H_2O$$

carbon dioxide | electron donor* | carbohydrate | water

Purple Sulfur bacteria (PSB)



H_2S



Purple non-Sulfur bacteria (PNSB)

Fe^{2+}

H_2S

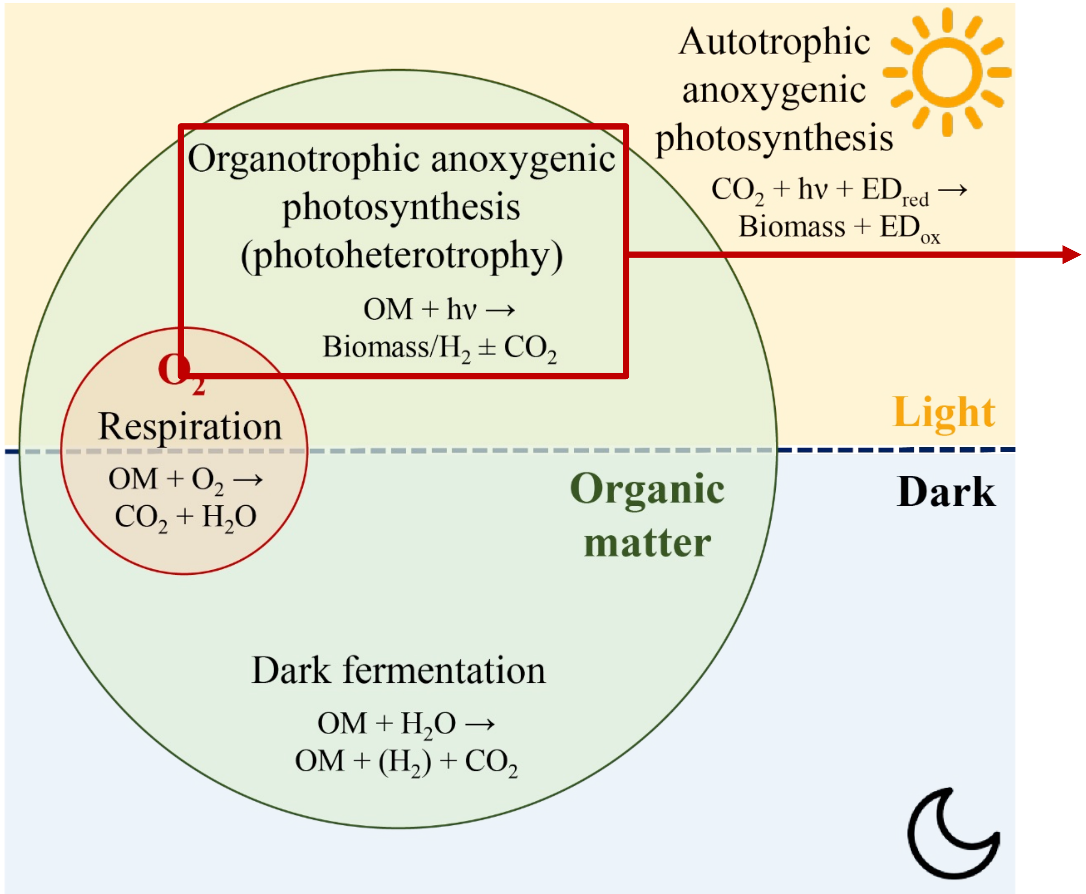
H_2

OM

Rhodobacter, Rhodopseudomonas, Blastochloris, Allochromatium, Rhodospirillum…

PPB are a Swiss-knife microorganism

Photoheterotrophy is key for resource recovery

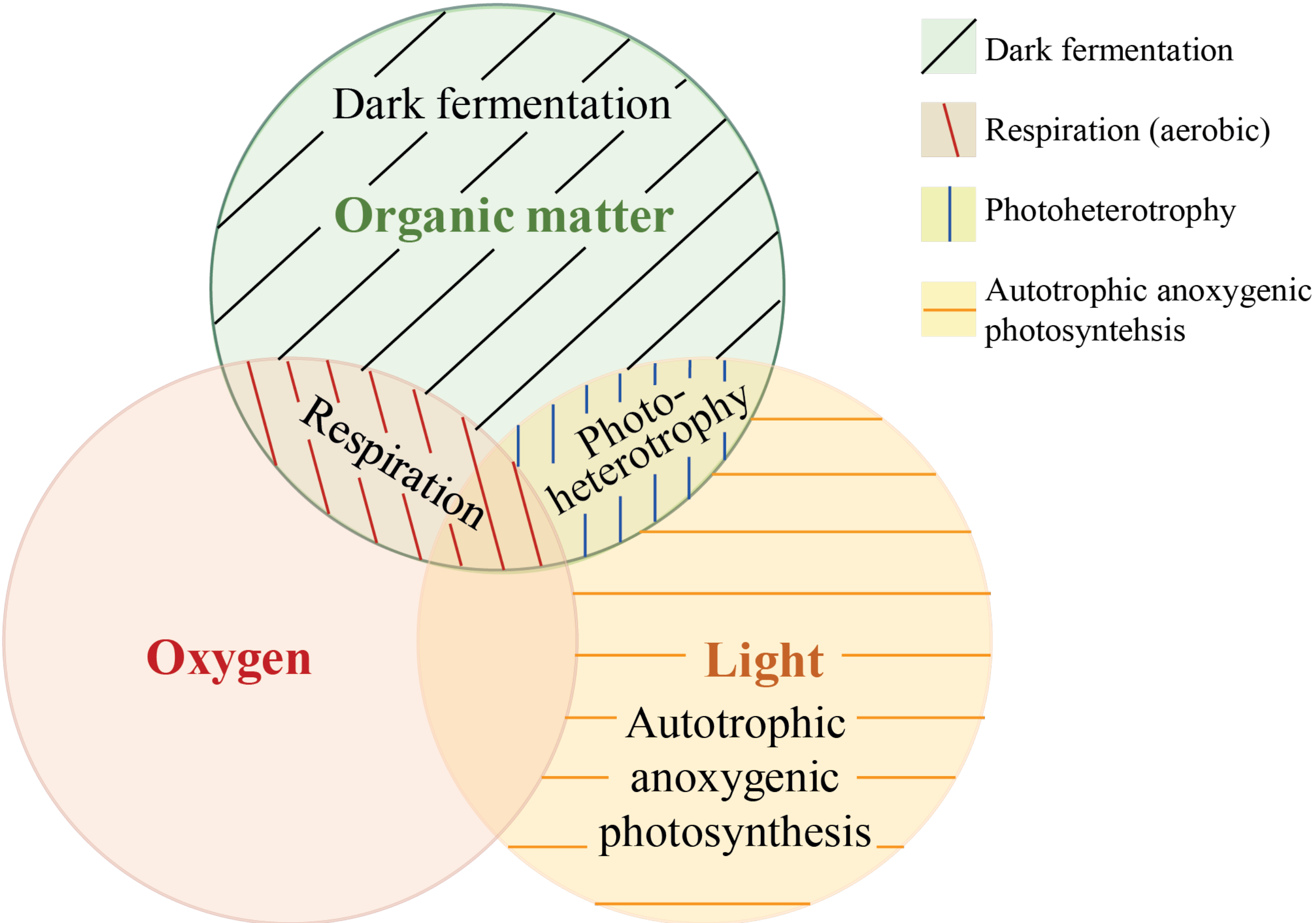


Capson-Tojo et al., Biotech. Adv., 2020

- Biomass yields close to 1 g $COD_{biomass}$·g $COD_{consumed}^{-1}$
- Simultaneous COD:N:P removal
- Near-infrared light: enrichment from virtually any waste stream
- ≈ 60% protein content

PPB are a Swiss-knife microorganism

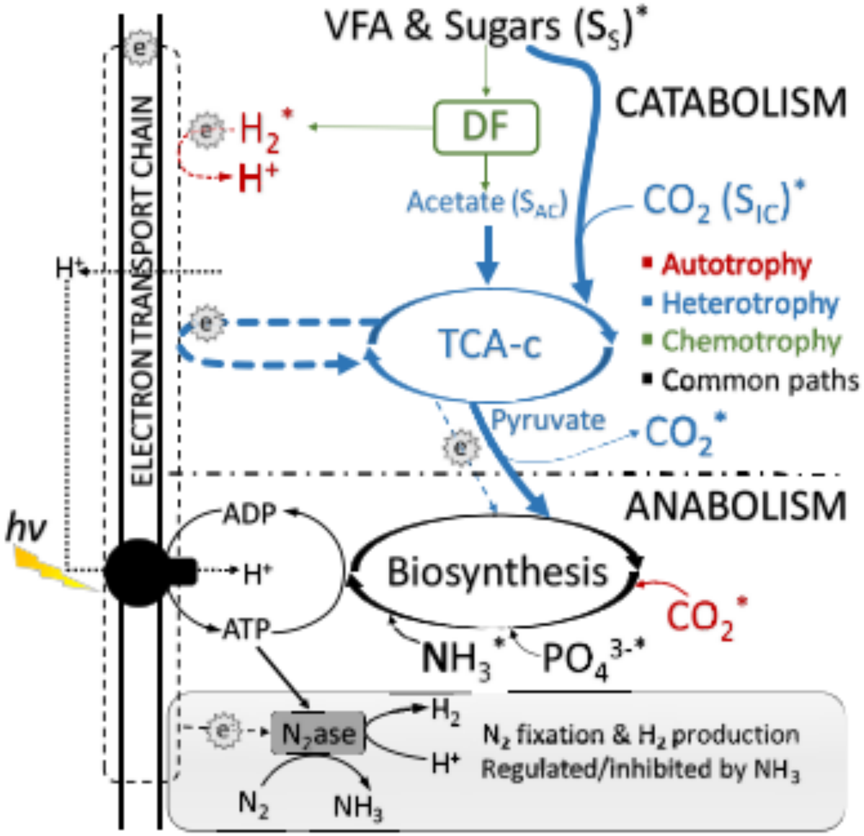
Metabolism = f(environmental conditions)



Capson-Tojo et al., Biotech. Adv., 2020

Modelling PPB systems

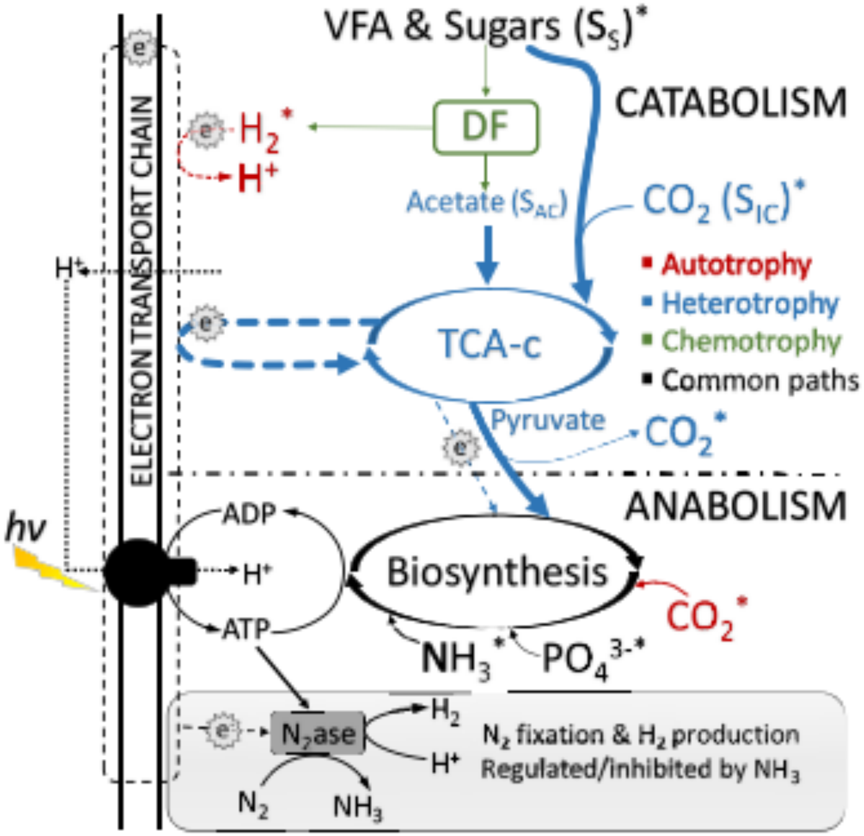
Challenge: metabolic diversity



Puyol et al., Water Res., 2017

Modelling mixed PPB systems outdoors

Challenge: metabolic diversity



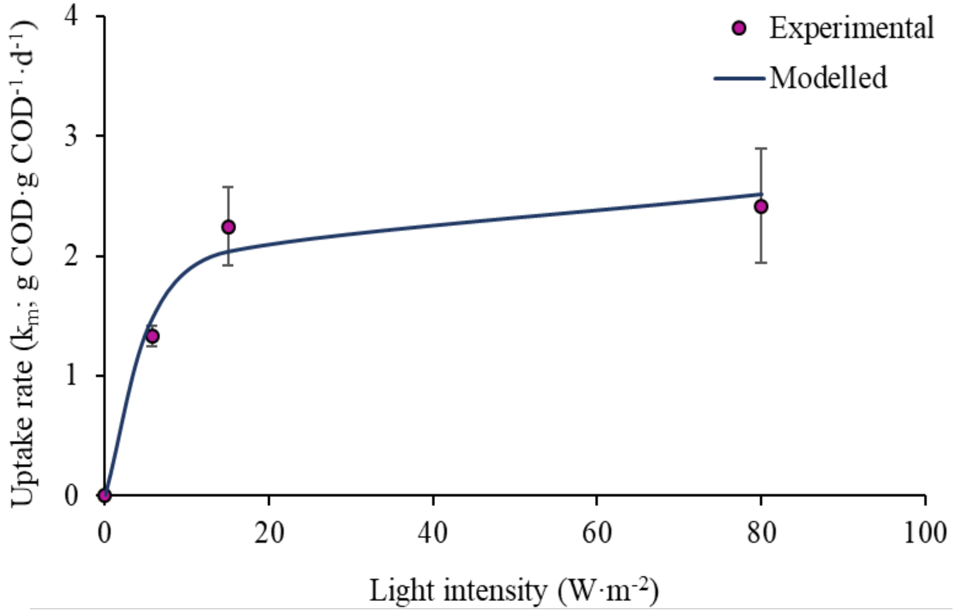
Puyol et al., Water Res., 2017

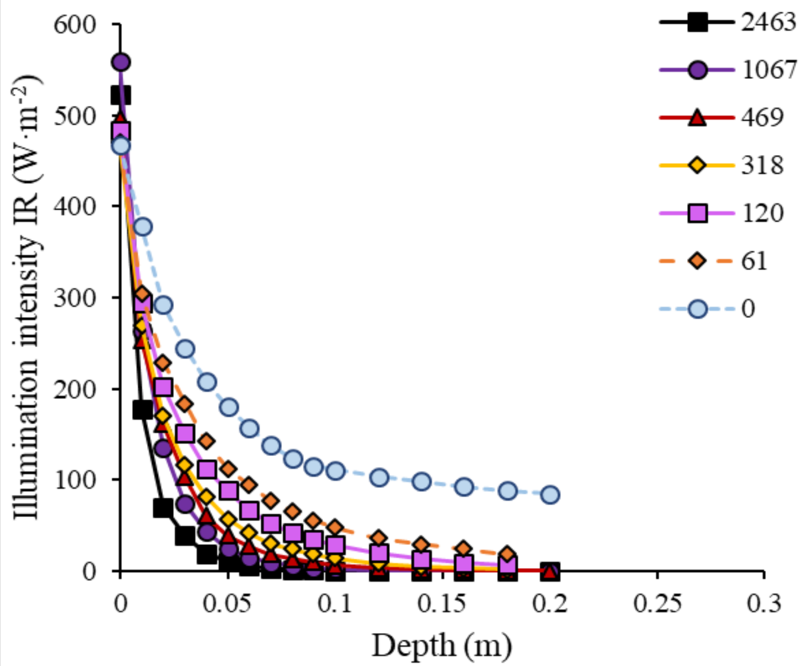
\+

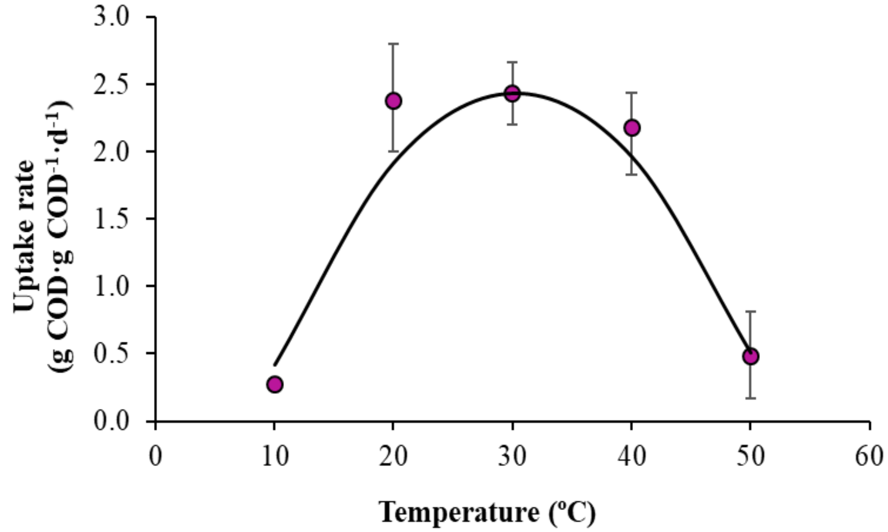
- Hydrolysis
- Aerobic PPB metabolism
- Microbial interactions (algae, aerobes, fermenters, SRB,…)
- Inhibition (O_2, NH_3, pH,…)
- Light attenuation and availability
- Variable temperature

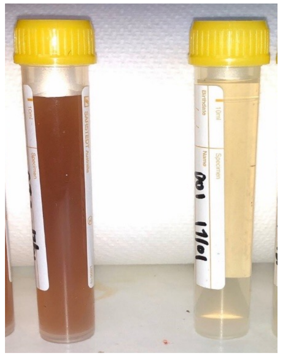
Modelling mixed PPB systems outdoors

Effect of environmental conditions (I, T, DO, etc.)





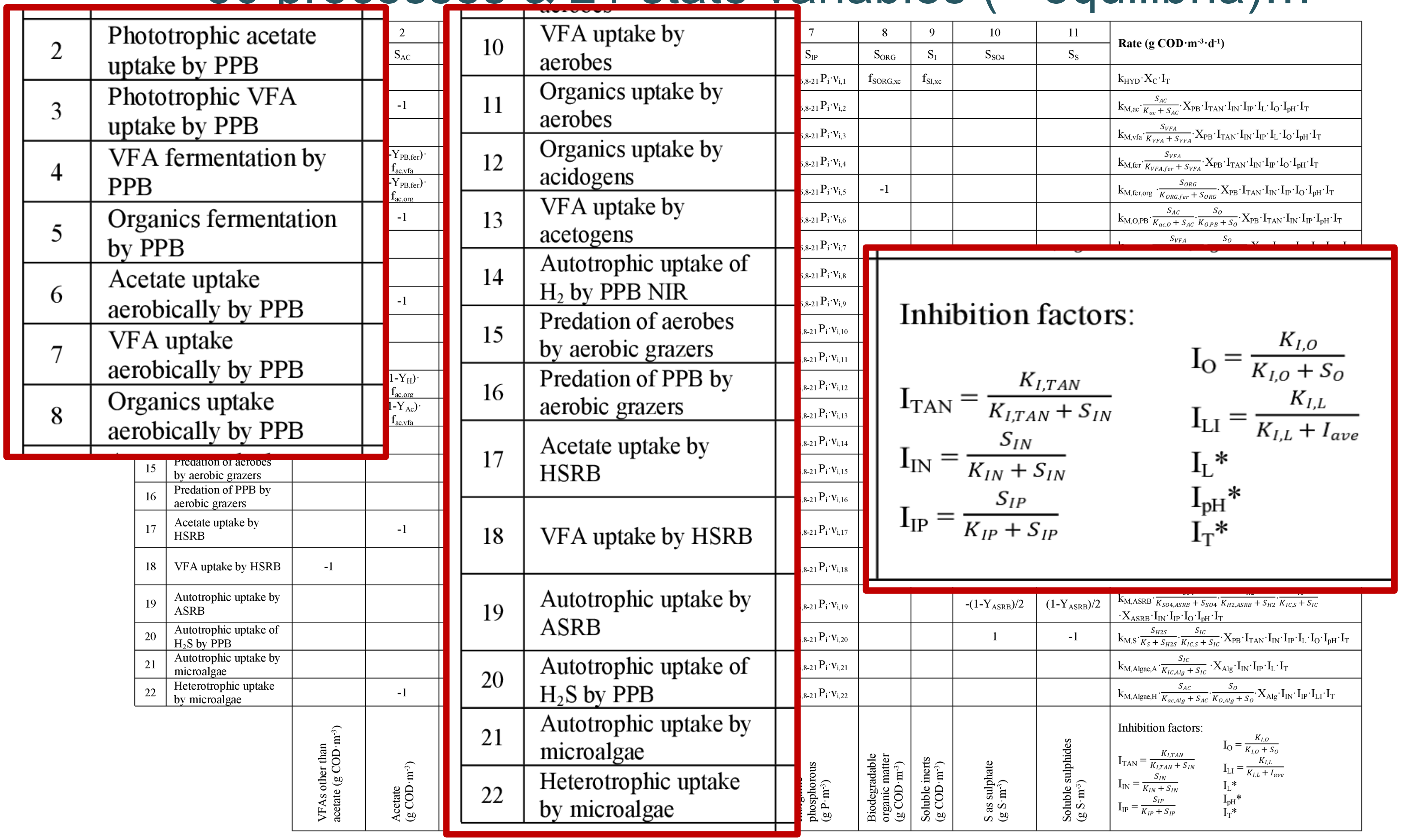




Capson-Tojo et al., Water Res., 2021, 2022, 2023

Modelling mixed PPB systems outdoors

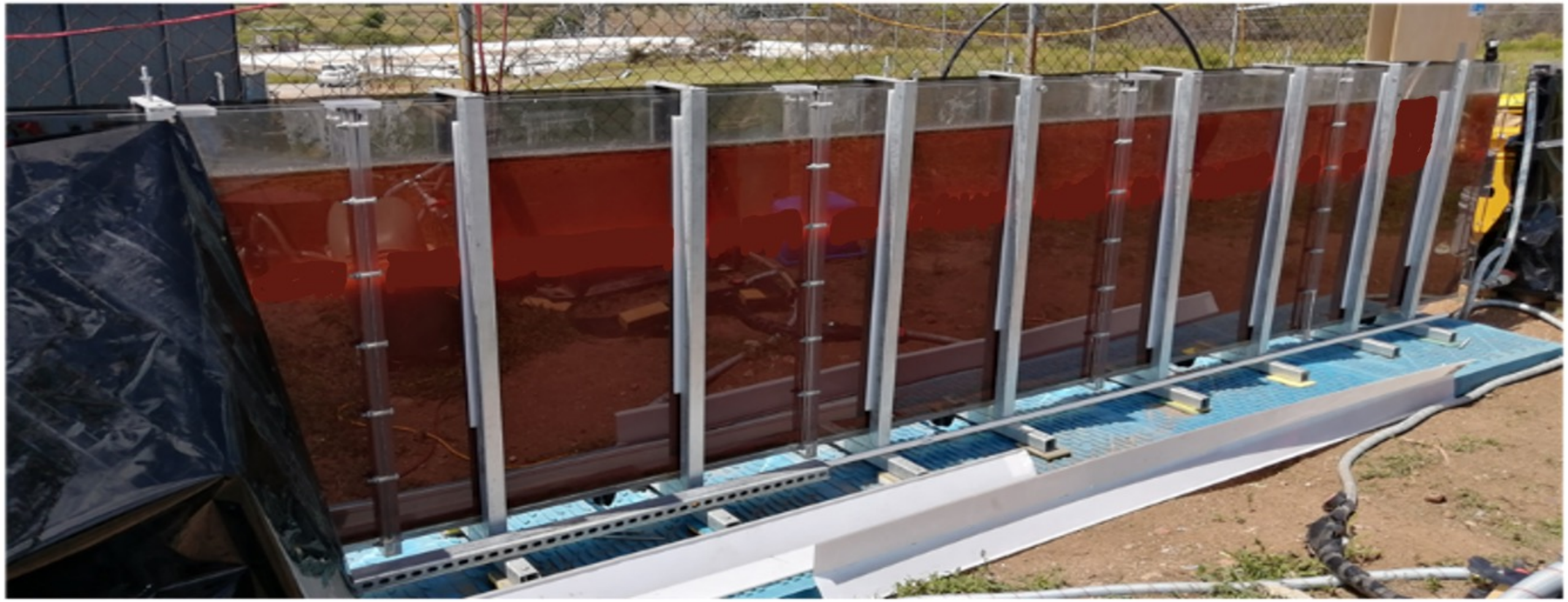
30 processes & 21 state variables (+ equilibria)…



Capson-Tojo et al., Water Res., 2023

Outdoors flat-plate pilot plant

Long-term data for calibration and validation



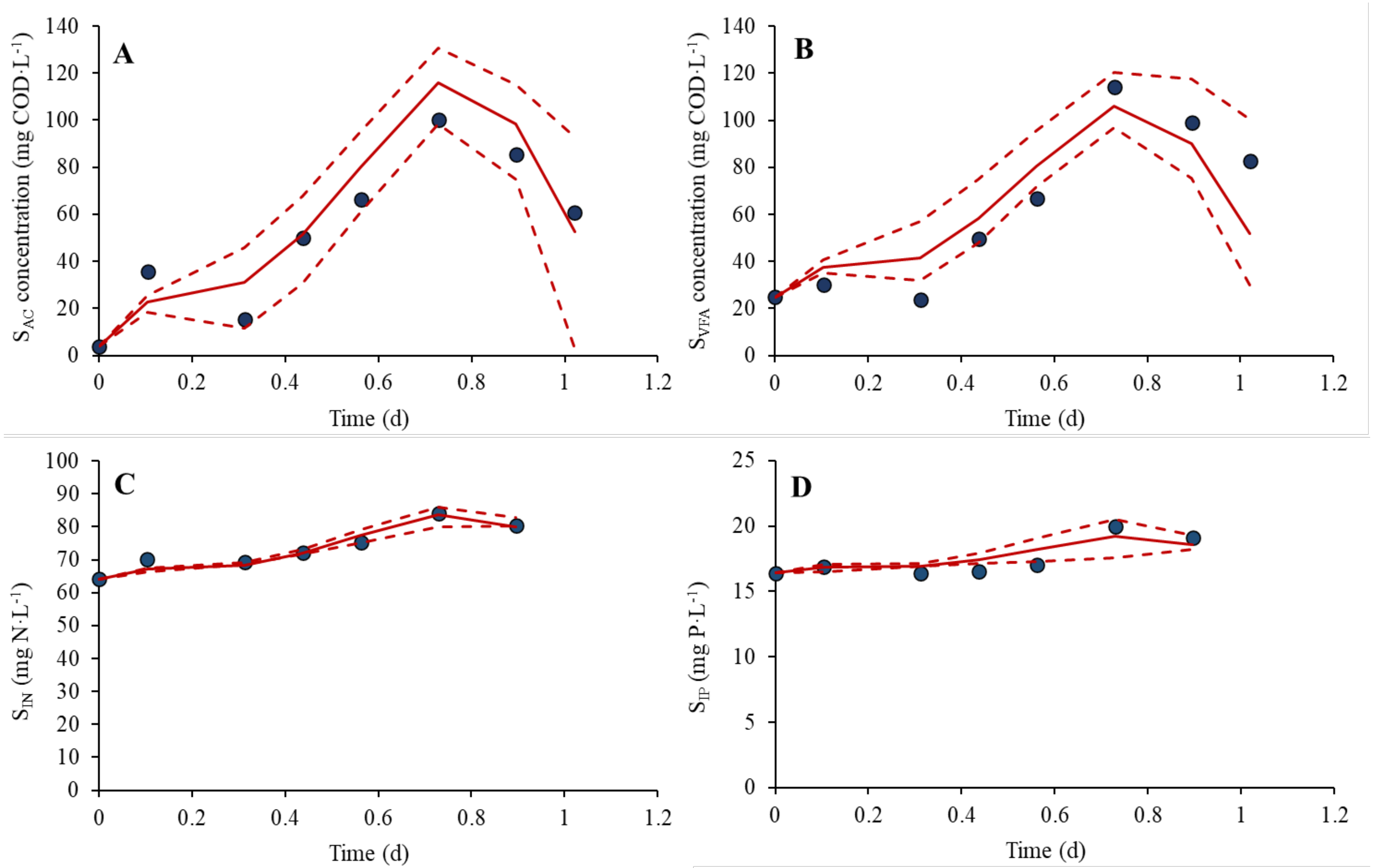
V = 950 L; HRT = 1.0-5.7 d; OLR = 0.8-2.2 g $COD \cdot L^{-1} \cdot d^{-1}$

T = 14-42 °C; I = 3-32 $MJ \cdot m^{-2}$

Hülsen et al., Water Res., 2022

Model calibration

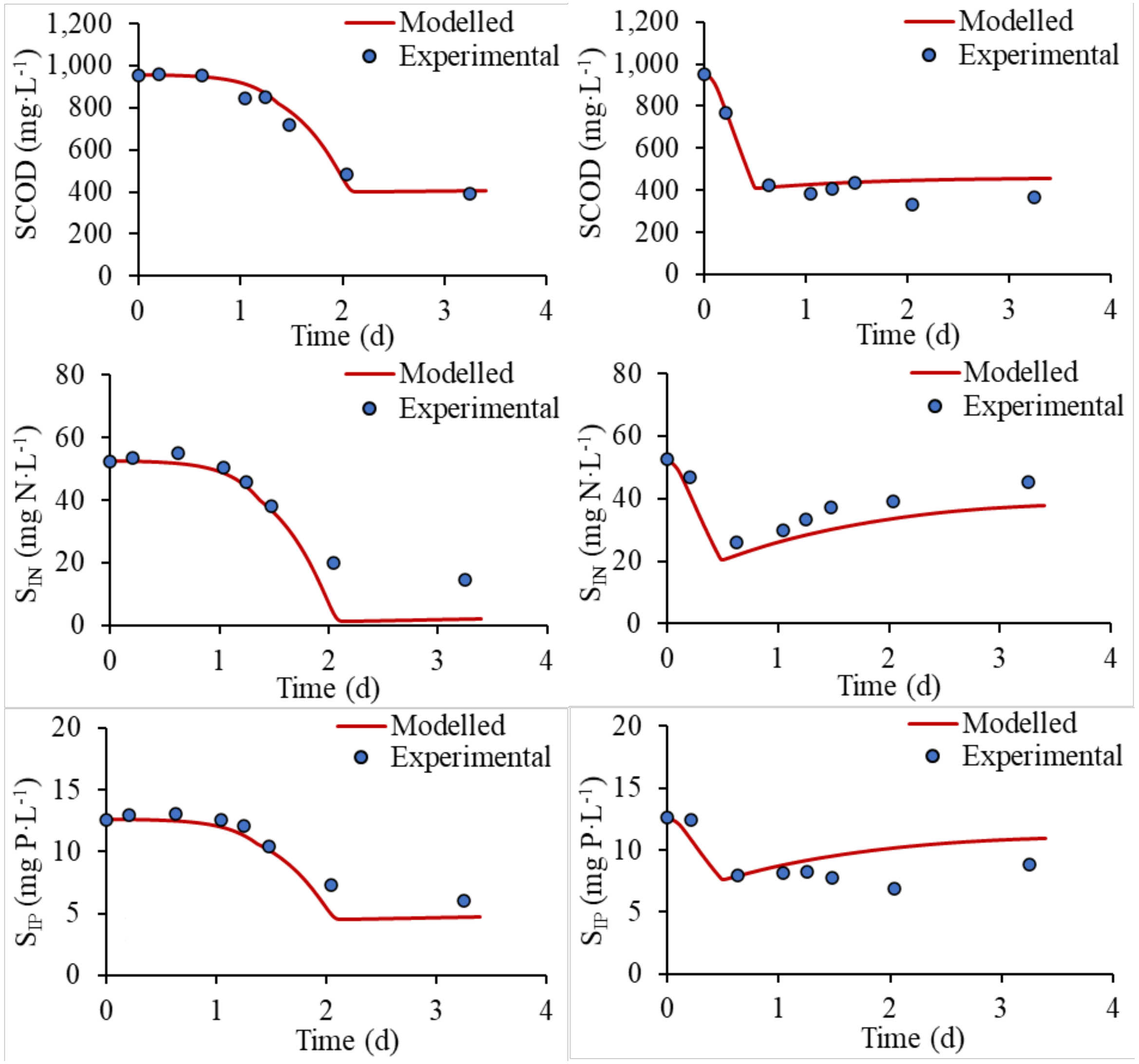
Data from pilot reactor



Capson-Tojo et al., Water Res., 2023

Validation using illuminated batch tests

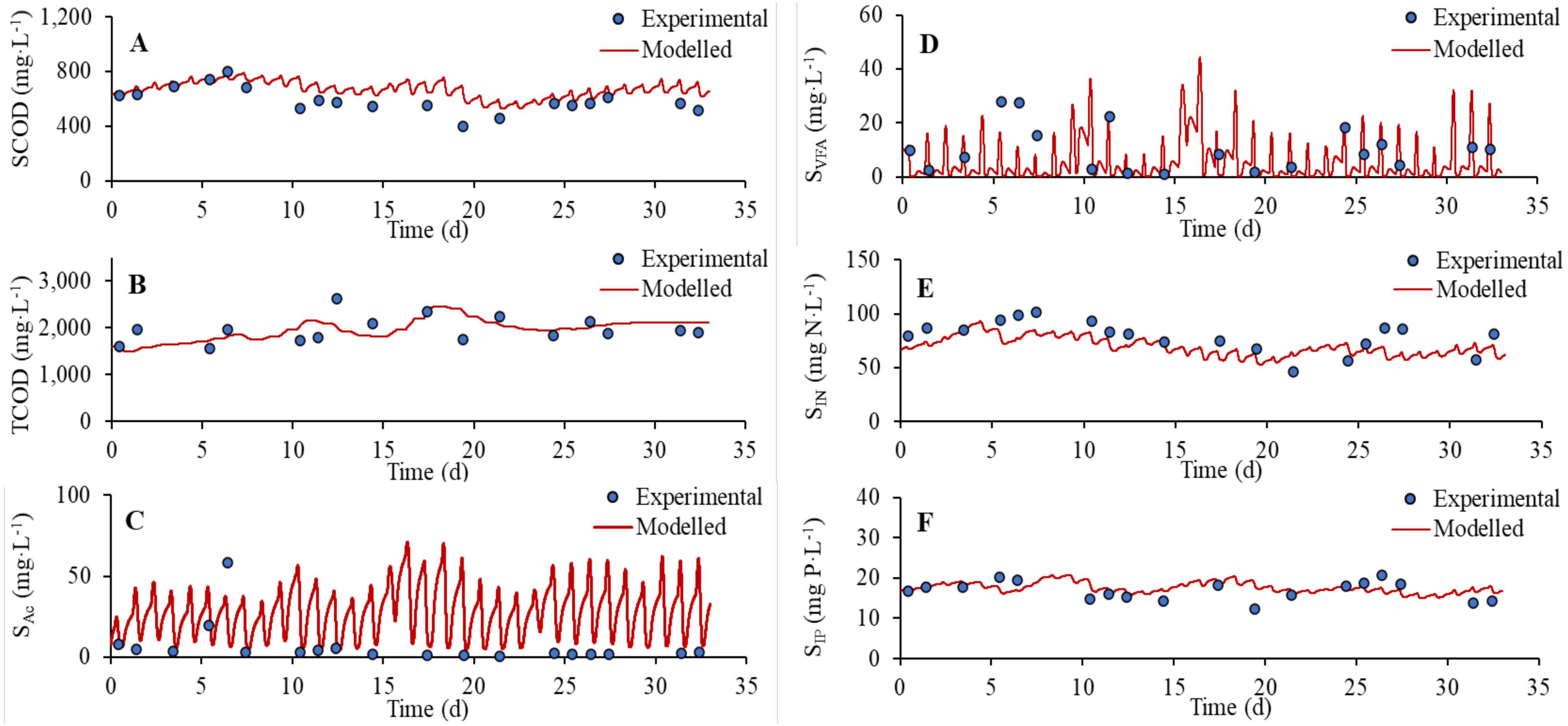
Anaerobic and aerobic



Capson-Tojo et al., Water Res., 2023

Validation using pilot data

Missing accurate daily cycles…



Capson-Tojo et al., Water Res., 2023

Take home message and perspectives

It works! But…

- PPB are anoxygenic phototrophs: photo**hetero**trophy
- Their diverse metabolism is a challenge
- Accurate overall predictions under anaerobic and aerobic illuminated conditions
- We could simulate optimal conditions for defined scenarios

- Validate interactions PPB-microalgae
- Validate interactions PPB-SRB
- Model including comprehensive light distribution
- Integrate with economic assessments and LCA

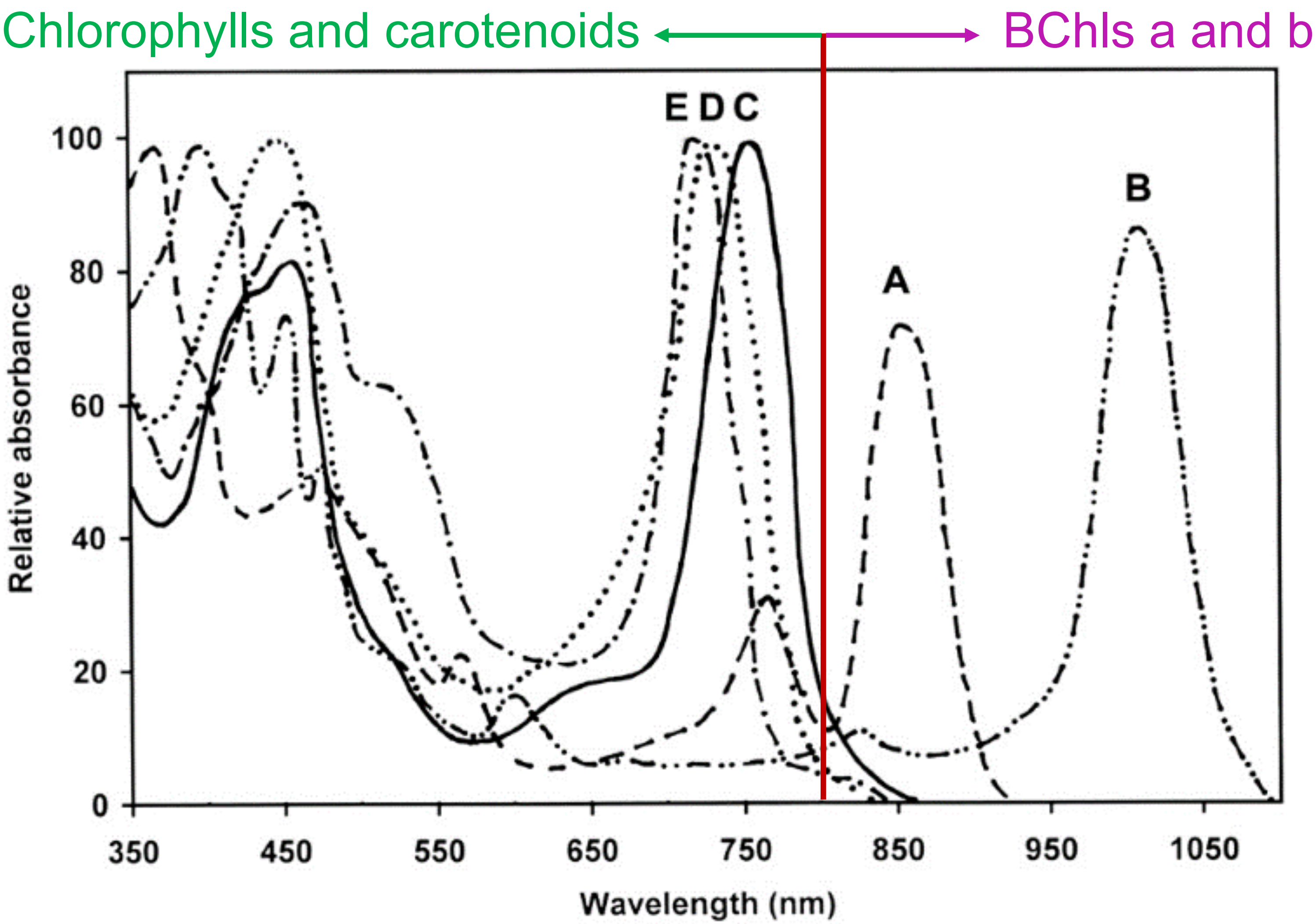
Thank you for your attention

Gabriel Capson-Tojo

December 21st, 2022

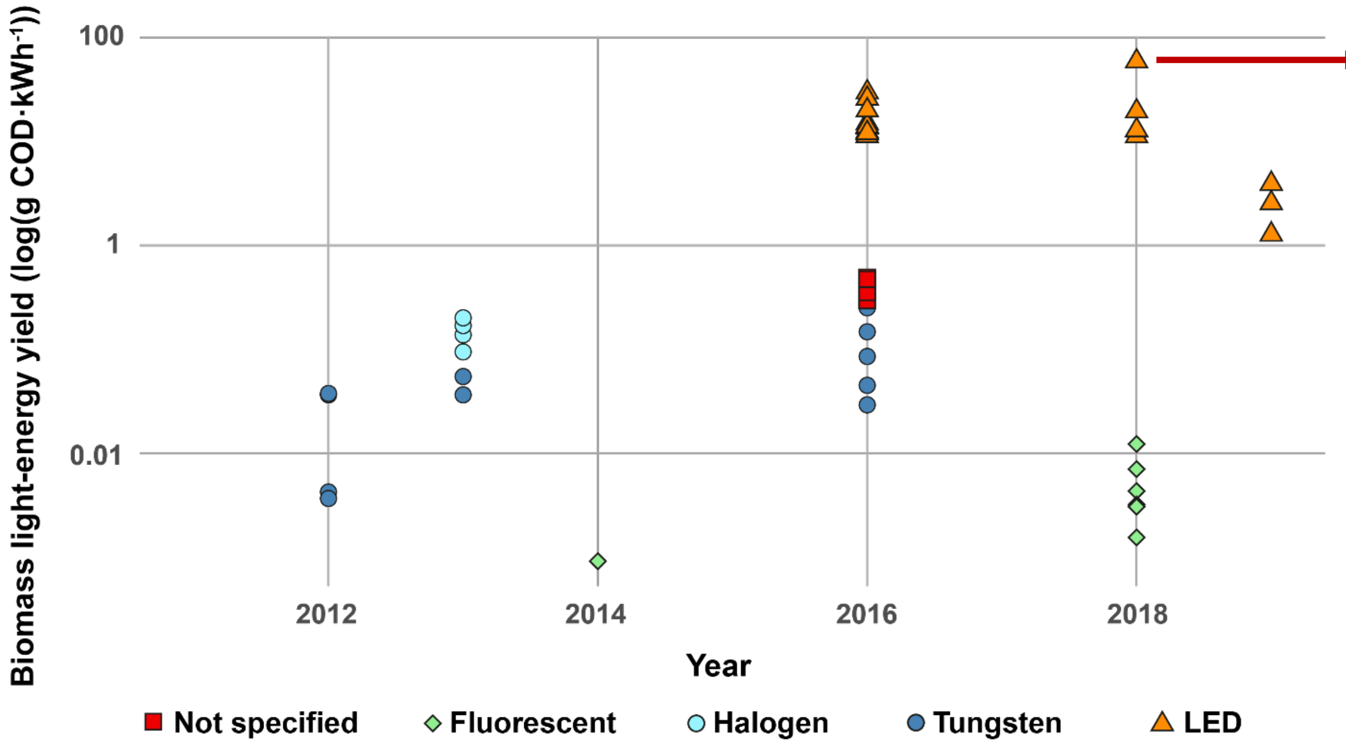
Photoheterotrophy is key for resource recovery

Light & PPB



NIR light availability is a challenge

Sunlight is needed



Capson-Tojo et al., Biotech. Adv., 2020

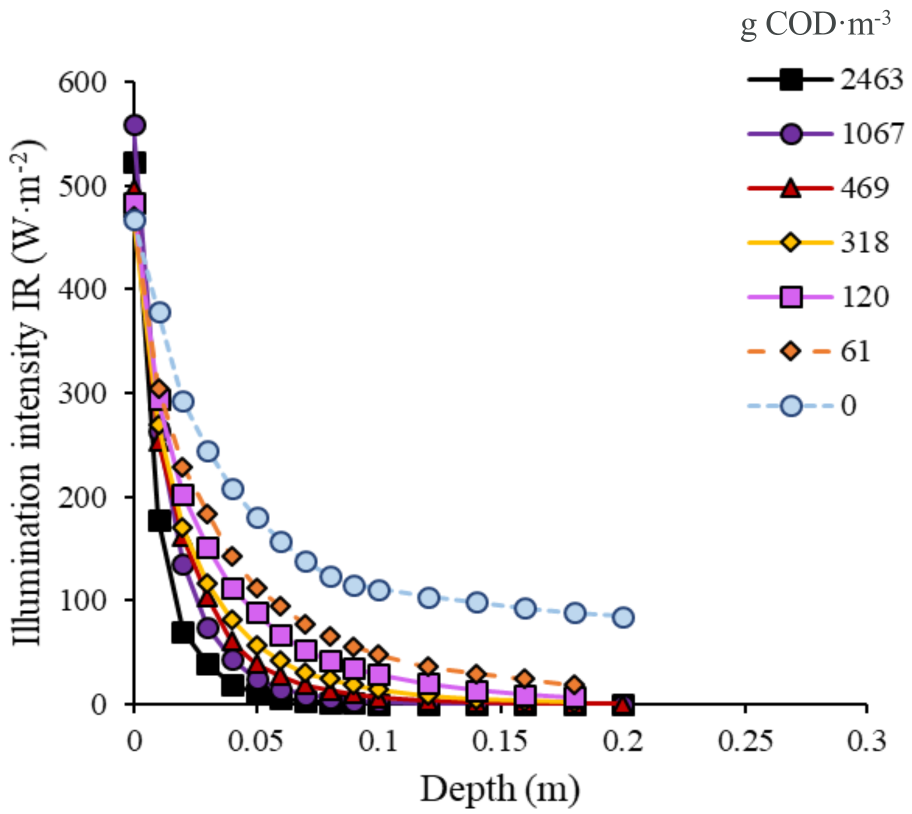
59 g COD·kWh^{-1}

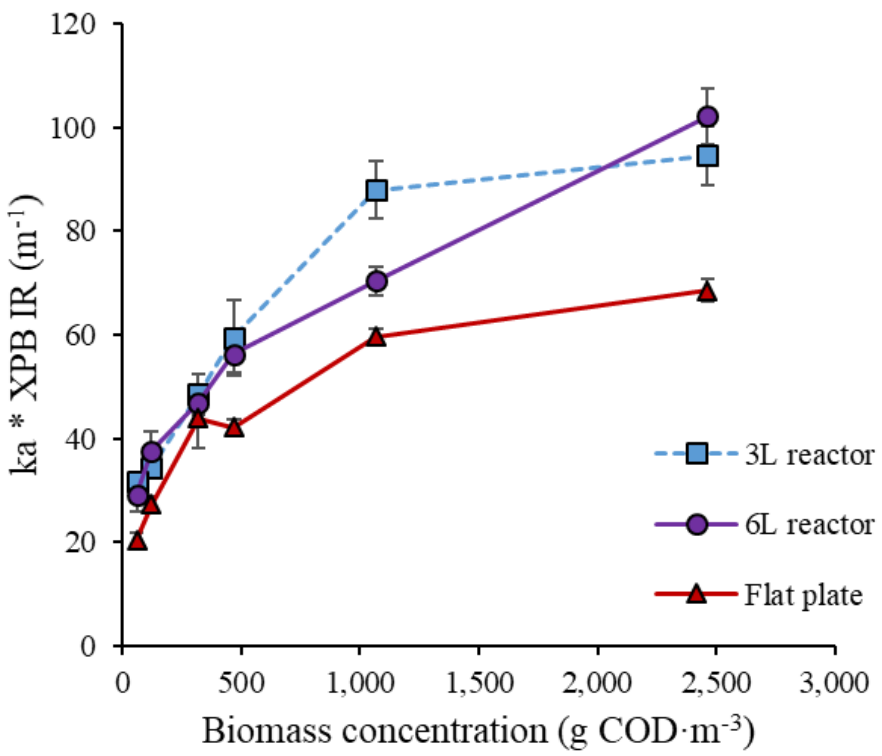
1.9 $\$\cdot kg_{biomass}^{-1}$

+ capital

NIR light availability is a challenge

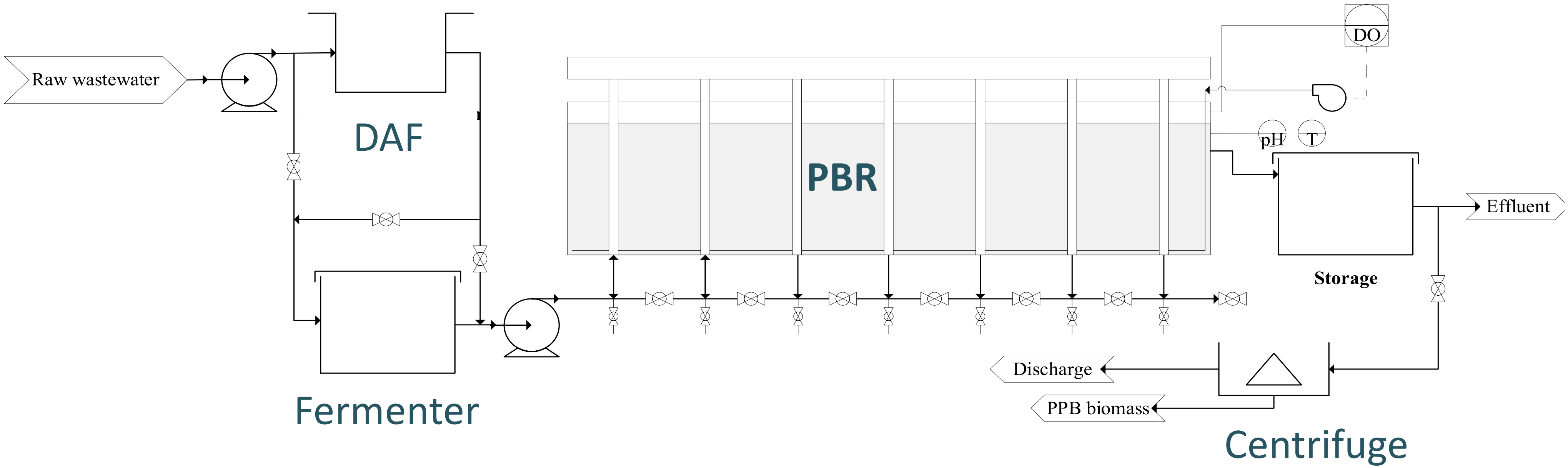
Light attenuation by H_2O and pigments





Capson-Tojo et al., Water Res., 2022

Outdoors flat-plate pilot plant



950 L; HRT of 1.0-5.7 d

T = 14-42 °C; I = 3-32 $MJ \cdot m^{-2}$

Hülsen et al., Water Res., 2022

	Units	Raw wastewater	DAF effluent*	Fermenter effluent**
TCOD	$mg \cdot L^{-1}$	4,288 (1,207)	1,916 (711)	1,976 (584)
SCOD	$mg \cdot L^{-1}$	1,826 (313)	1,045 (343)	1,064 (350)
VFA-COD	$mg \cdot L^{-1}$	68 (47)	122 (87)	513 (324)
TS	$mg \cdot L^{-1}$	2,992 (877)	1,486 (679)	1,553 (608)
VS	$mg \cdot L^{-1}$	2,192 (599)	960 (505)	903 (533)
TKN_{total}	$mg \cdot L^{-1}$	232 (74)	124 (47)	132 (34)
$TKN_{filtered}$	$mg \cdot L^{-1}$	158 (23)	94 (30)	105 (24)
NH_4^+-N	$mg \cdot L^{-1}$	14 (5.4)	21 (12)	75 (31)
TP_{total}	$mg \cdot L^{-1}$	40 (13)	25 (11)	29 (7.4)
$TP_{filtered}$	$mg \cdot L^{-1}$	30 (8.4)	20 (9.1)	23 (5.7)
PO_4^{3-}-P	$mg \cdot L^{-1}$	25 (9.3)	19 (8.5)	22 (5.9)

Period	I	II	III	IV	V	VI	VII	VIII
Biomass productivity ($g\ TS \cdot m^{-2} \cdot d^{-1}$)	30±4.1	63±14	61±8.0	75±9.1	126±21	89±14.5	86±18	72±4.1
Biomass productivity ($g\ VS \cdot m^{-2} \cdot d^{-1}$)	25±3.8	38±12	41±7.2	54±7.4	84±12	59±10	44±15.6	38±3.8
Estimated biomass productivity ($g\ COD \cdot m^{-2} \cdot d^{-1}$)	9.1±4.0	18.2±10	11.6±3.2	18.7±5.3	38±9.6	11.1±1.2	19.5±10	14.3±5.6
SCOD removal (%)	54±17	48±12.8	40±6.0	33±9.7	72±4.1	39±3.8	67±14	46±11
VFA removal (%)	99±0.7	91±4.5	82±6.7	67±11	96±8.3	91±3.4	87±7.9	85.1±8.7
TKN removal (%)	77±4.2	46±12	45±7.8	34±9.4	58±2.3	30±4.4	53±9.3	37±8.8
TP removal (%)	44±5.7	30±11	37±7.6	28±11	29±4.4	37±16	45±15	34±14
TS content ($g \cdot L^{-1}$)	2.2±0.3	1.3±0.2	1.2±0.2	1.7±0.3	2.5±0.4	1.7±0.3	1.7±0.4	1.5±0.1
OLR ($g\ COD \cdot L^{-1} \cdot d^{-1}$)	-	1.3±0.3	1.0±0.2	2.2±0.5	1.3±0.3	1.1±0.1	0.8±0.4	0.8±0.3
SCOD removal rate ($g \cdot L^{-1} \cdot d^{-1}$)	0.14±0.06	0.4±0.18	0.20±0.1	0.40±0.1	0.7±0.38	0.2±0.03	0.4±0.24	0.3±0.12
TKN removal rate ($mg \cdot L^{-1} \cdot d^{-1}$)	21±4.5	32±9.4	25±8.2	35±9.6	36±20	27±6.8	25±9.6	22±5.9
TP removal rate ($mg \cdot L^{-1} \cdot d^{-1}$)	2.7±0.8	4.1±1.5	4.3±1.3	7.5±3.4	4.5±1.2	4.8±1.1	5.4±3.5	3.3±2.1

AGENDA AND HOUSEKEEPING

Speaker 1
Francisco Gabriel Acién Fernández
(Universidad de Almería, Spain)

Speaker 2
Francesca Casagli (INRIA, Italy)

Speaker 3
Borja Valverde-Pérez (Technical University of Denmark)

Speaker 4
Gabriel Capson-Tojo (INRAE, France)

Q&A Session Moderator: *Elena Ficara (Politecnico di Milano, Italy)*

- This session is being recorded;
- Microphones and cameras have been disabled due to the large number of attendees;
- The normal chat function is disabled;
- Please put any questions and comments you may have in the Q&A (icon to the low right in Zoom) and we will do our best to answer them during the session (in writing or orally).

CLOSING REMARKS

Great thanks to all presenters for a wonderful show!

Thanks to members of the MIA MC for arranging it.

Look out for MIA's NEXT webinar in February 2023:

"State-of-the-Art in Physico-Chemical Modelling"

If you have ideas for your own future webinar then contact MIA MC and we will help you make it happen!

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IWA MIA webinar on
Modelling of phototrophic systems for resource recovery from wastewater

Wednesday December 21, 2022

Extract from Q&A session during the webinar

Questions answered in writing

Abraham James (Guest)   15:36
Thank you very much for this webinar. It's quite revealing.
1. The manure used for microalgae cultivation, was it first subjected to anaerobic treatment before use or it was just made in solution form and deployed, and what's the proportion of solvent to manure if the later applies?

Francisco Gabriel Acién Fernández (Guest)   15:40
Manure must be pretreated only to remove solids, the supernantant with lower turbidity as possible can be used directly as nutrients source in microalgae cultures. After anaerobic digestion the digestate can be also used appliying the same principle, lower turbidity as possible. Please remain that it is always neccesary to adjuts the dosage of manure or whateever other effluent in the range of providing 100 mgN/L...

Eric Valdés (Guest)   15:44
My question is for Francesca. It appears clear that an external source of alkalinity improved the system's overall performance, but I imagine it would also compromise the economical feasibility of the process. Have you assessed the effect of needing this external source on the economical costs? Thank you for the presentation, very interesting and great modeling results.

Francisco Gabriel Acién Fernández (Guest)   15:48
I think that this is not a very general scenario. Most of the wastewaters contains much more alkalinity... In Almeria we never observe this phenoemna but the inorganic carbon at the inlet is up to 120 mgC/L.

Francesca Casagli (Guest)   16:04
Hello Eric, thank you for your question! We performed an economic analysis (available on a published work on Environmental Science and Technology) considering addition of NaOH and its cost. Then we considered the operational cost for treating 1 Kg of nitrogen and the gain we have in TAN removal rate adding alkalinity (it was approximately 30% for piggery digestate). In the end the computed cost of alkalinity addition was 0.013 $/m2/d, counterbalanced by the increse in nitrogen removal rate (treating an additional 30% of nitrogen with additional alkalinity has a value estimated to be 0.03 $/m2/d).

Davide Carecci (Guest) 15:50
I was wondering which type of digestate was the one used in the SABANA project, in terms of AD feedstocks used. How have it been treated for the reduction of turbidity? Did you use any coagulant/flocculants? If centrifugation was performed, didn't you face severe P precipitation leading to an unbalanced N:P ratio?

Francisco Gabriel Acién Fernández (Guest) 15:53
We uses digestate from anaerobic digestion of pork manure. It was dcanted and centrifugated to remove solids. No coagulants were used. No P was removed from the systems, we dint observe that...

Olivier BERNARD (Guest) 15:51
Question for Borja: how do bacteria, particulate (apart from algae) and dissolved organic matter also affect the light extinction coefficient?

Borja Valverde-Pérez (Guest) 15:59
We have run tests with both algae and mixtures of algae and bacteria biomass. At same levels of TSS, the mix with algae and bacteria yielded higher attenuation coefficients. We assessed this in the range of 100 to 300 mg/L - not too wide range. In any case, compared to cultivation in synthetic media (i.e., no organics dissolved), the attenuation coefficient shows less variabiliy. We can discuss it at the end if it's not clear.

Questions answered orally

Abraham James (Guest) 15:39
I'm currently performing a microalgae based wastewater treatment using photobioreactor under a natural outdoor condition. Due to weather variability, I've had repeated cloudy condition and this corresponds with high dissolved oxygen. I observed the nitrificatiin-denitrification phase took a while. Could this be as a result of repeated high concentration of dissolved oxygen in the system?

Olivier BERNARD (Guest) 16:10
Do you have included this in your light extinction model ?

Ishin Kaya (Guest) 16:12
It looks like that all experiments conducted in shallow reactors (< 0.4 m depth) to maximize the natural light penetration. For alagal-bacterial consortia reactors, Footfrint is very

important. Is there any interest from the panelists on working on deeper CSTR reactors using supplementary LED lighting?

Ishin Kaya (Guest) 16:14
P.S. We have developed mixing-aeration tool for deeper algal-bacterial reactors if anyone interested: www.mixanox.com/application
Ishin Kaya (Guest) 16:15
https://www.mixanox.com/applications

Abraham James (Guest) 16:16
If photoinhibition occurs during cultivation, is there a possibility of microalgae survive a repeated exposure.? Colour change from green to yellow a day after 48 degree Celsius was recorded. Colour restoration was observed under 24 hours, and soon after, 49 degree Celsius was observed without any colour change. The cultivation was done in a photobioreactor

Davide Carecci (Guest) 16:17
Have it been any interest/efforts using model-based dynamic DoE (design of experiment) to help performing optimized experiments for parameter calibration? Thank you

Ishin Kaya (Guest) 16:18
Have you used MBBR media in a photobiorector?

Anish (Guest) 16:24
Thank you for the nice presentations. happy holidays!

Ishin Kaya (Guest) 16:24
AlgaeWheel (algaewheel.com) technology uses MBBR media in shallow reactors (inside the wheel), my interest is on using MBBR media freely floating in deeper ptotobioreactors. Feel free to reachout at https://www.linkedin.com/in/ishinkaya/

Ishin Kaya (Guest) 16:24
Thank you for the great webinar. :)

Prof. Prem raj Pushpakaran (Guest) 16:27
From, Prof. Prem raj Pushpakaran
(drpremrajp@nitc.ac.in) -- thanks