

The IMAP project: how to integrate microalgae culturing in conventional wastewater treatment plant Pilot scale results

Valeria Mezzanotte
Università degli Studi di Milano Bicocca – DISAT

Elena Ficara
Politecnico di Milano -DICA



- **Bresso WWTP (Milano, Italy)**
- Water line
- Mechanical pre-treatment (screening, grit/oil removal)
- Primary settling
- Activated sludge pre-denitrification/nitrification
- Secondary settler
- Tertiary treatment (U.V. disinfection)
- Sludge line
- Mesophilic anaerobic digestion with 2 CHP units (220 and 320 kW_{el})
- Centrifuge for sludge dewatering

Centrate (digestate supernatant)



NH ₄ -N (mg/L)	PO ₄ -P (mg/L)	TSS (mg/L)	OD 680nm	COD (mg/L)	EC (µS/cm)	pH
244 ±78	5.7±0.8	83±40	0.1±0.1	112±34	1490±270	8.2±0.3

Pilot scale installation

Raceway $6 \times 1 \times 0.12\text{--}0.35\text{ m}$

2 channels (each one 5m long and 0.5 m wide)

$S = 5.78\text{ m}^2$

$V = 1,200\text{ L}$ on average

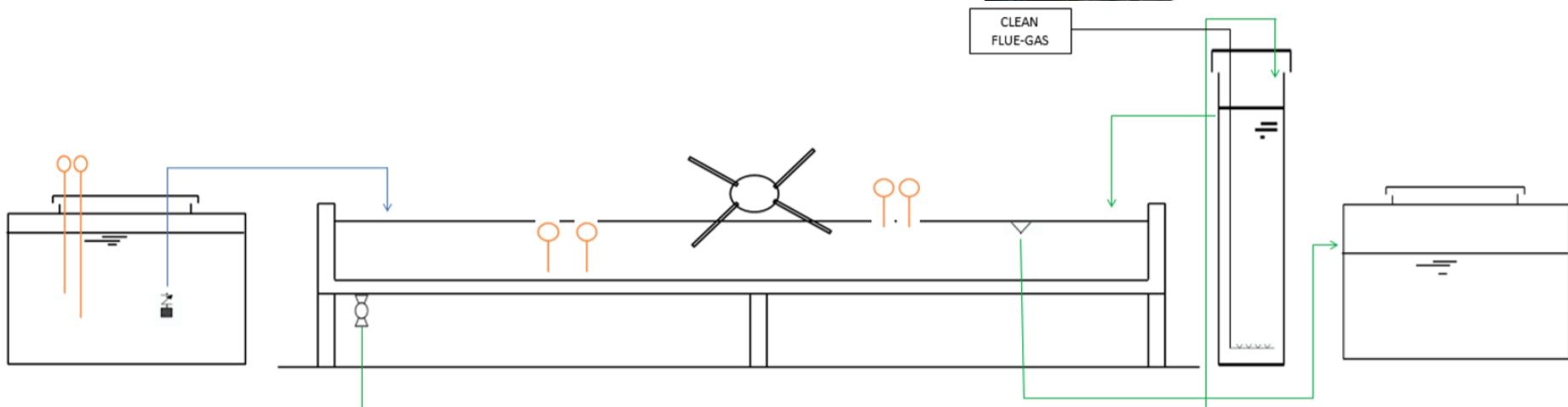
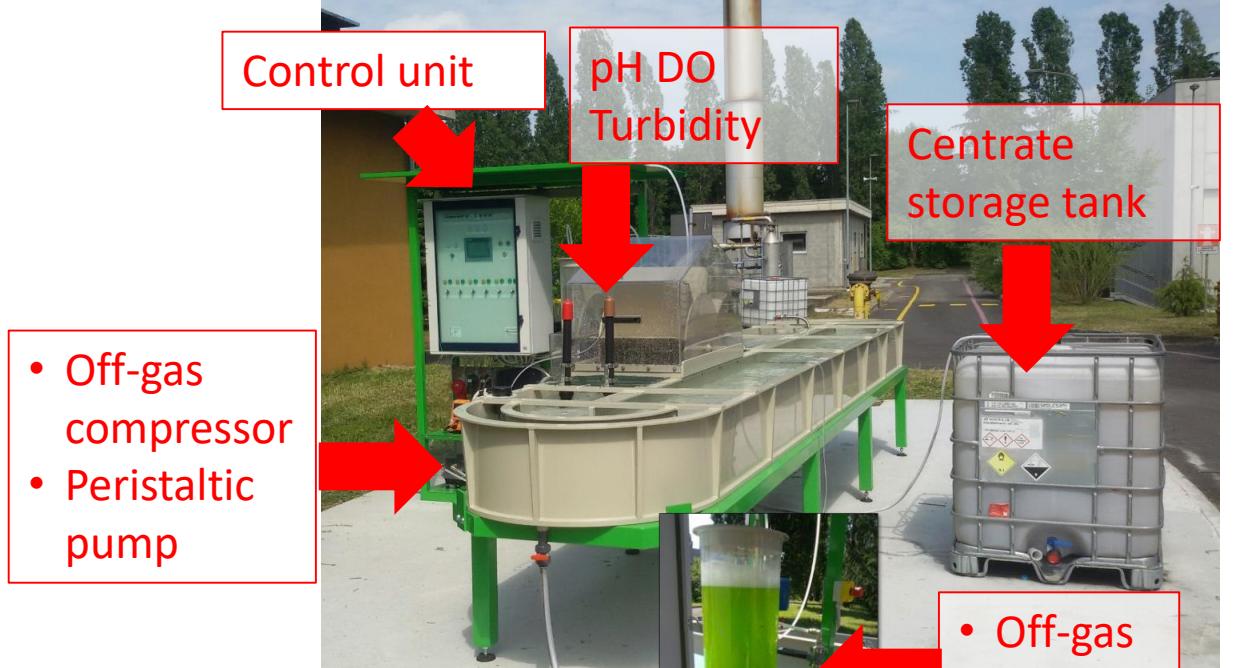
Main components:

- Probes (pH, DO, T, level, turbidity, NH_4 and NO_3)
- Paddle wheel at 4 rpm
- Gas-transfer unit
- pH-control
- Feeding pump

$Q_{in} = 115\text{ L/d}$

HRT = 10 d

Started on April 2017

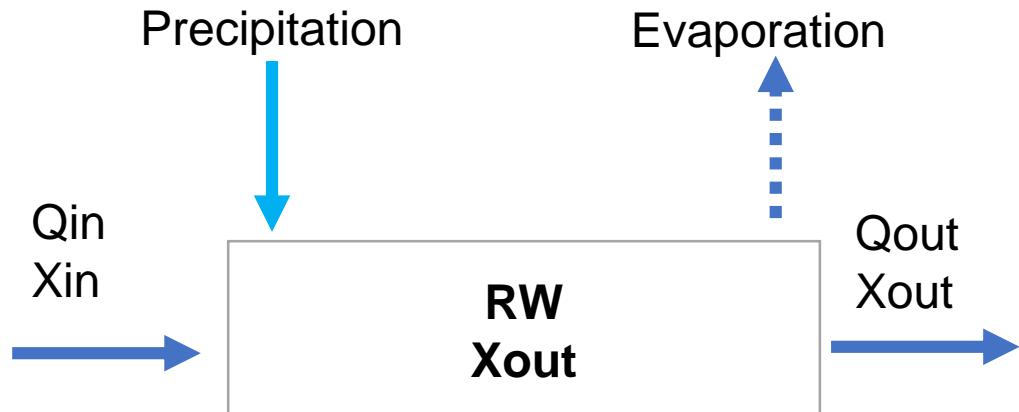


Monitoring and data processing

Analyses on grab samples IN and OUT

- TSS, VSS,
- OD₆₈₀, cell counts
- N and P
- COD

Raceway mass and water balance



Evaporation estimation: Penman's equation

$$E = \frac{\Delta * \text{net radiation} + \gamma * \text{mass transfer}}{\Delta + \gamma}$$

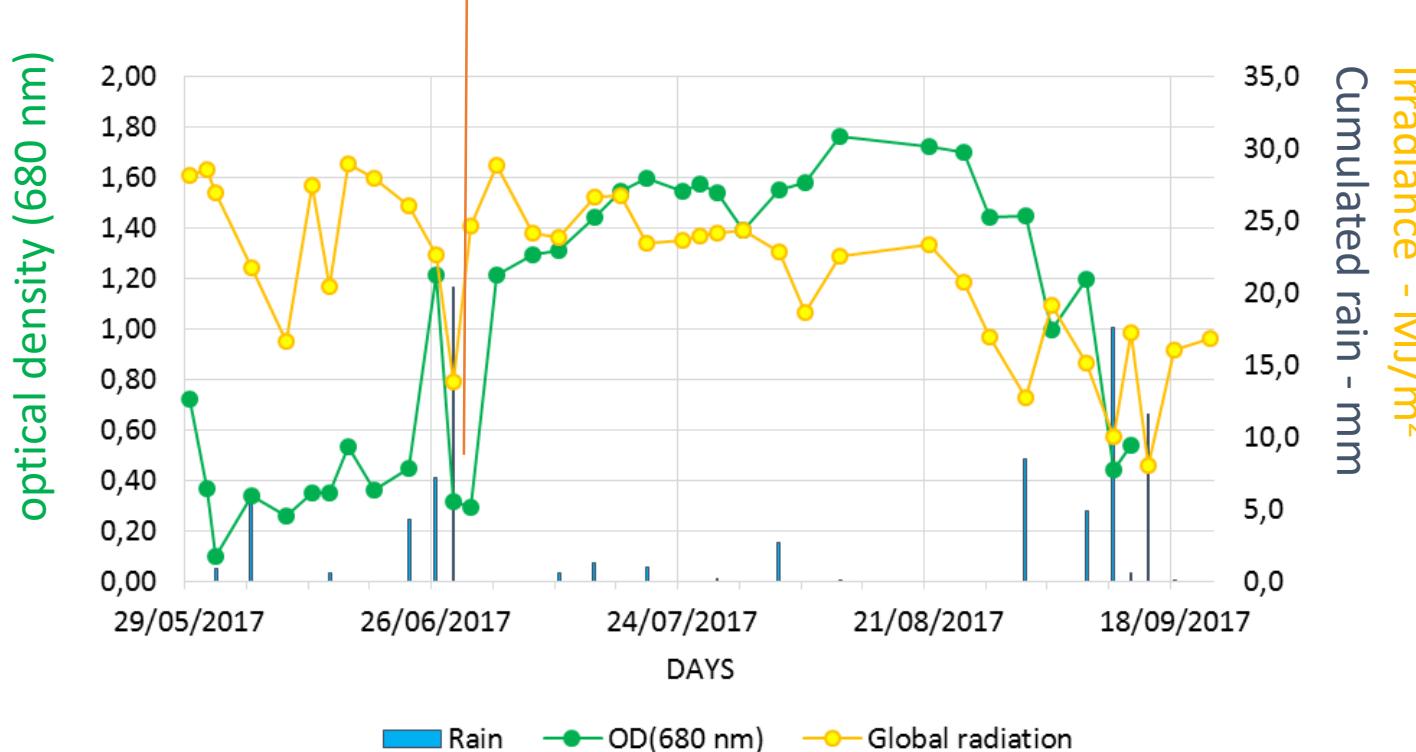
$$= \frac{\Delta * (Rn - G) + \gamma * \lambda_v * (1 - 0.536 * u) * (1 - W)}{\lambda_v * (\Delta + \gamma)}$$

$$Q_{out} = Q_{in} + P - E_v [L/d]$$

$$\frac{d(X_{outA} * V)}{dt} = Q_{in} * X_{inA} - Q_{out} * X_{outA} \mp r_A$$

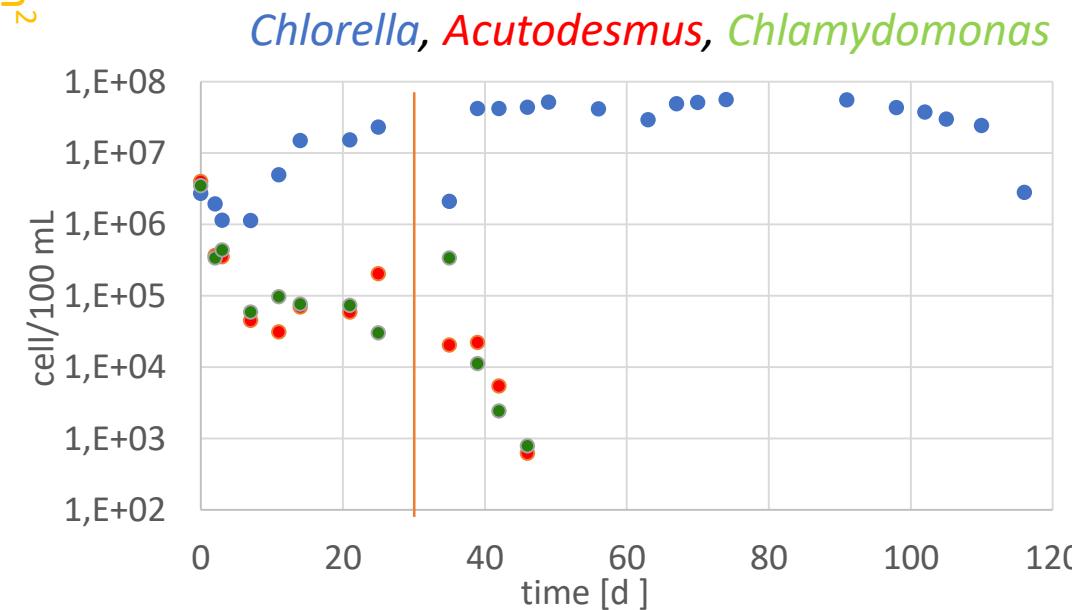


Results – 2017 : algae growth



Areal productivity
4 - 10 gTSS/m²/d

Cell Counts



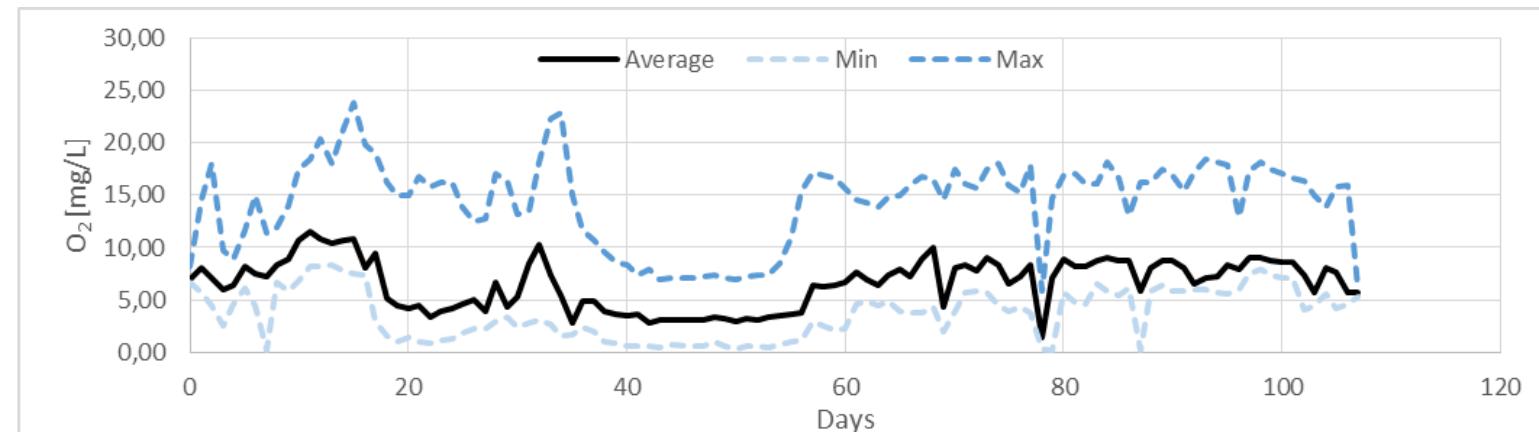
Results – 2017: on line probes

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Oxygen trend:

Influenced by:

- photosynthesis
- bacteria oxygen uptake

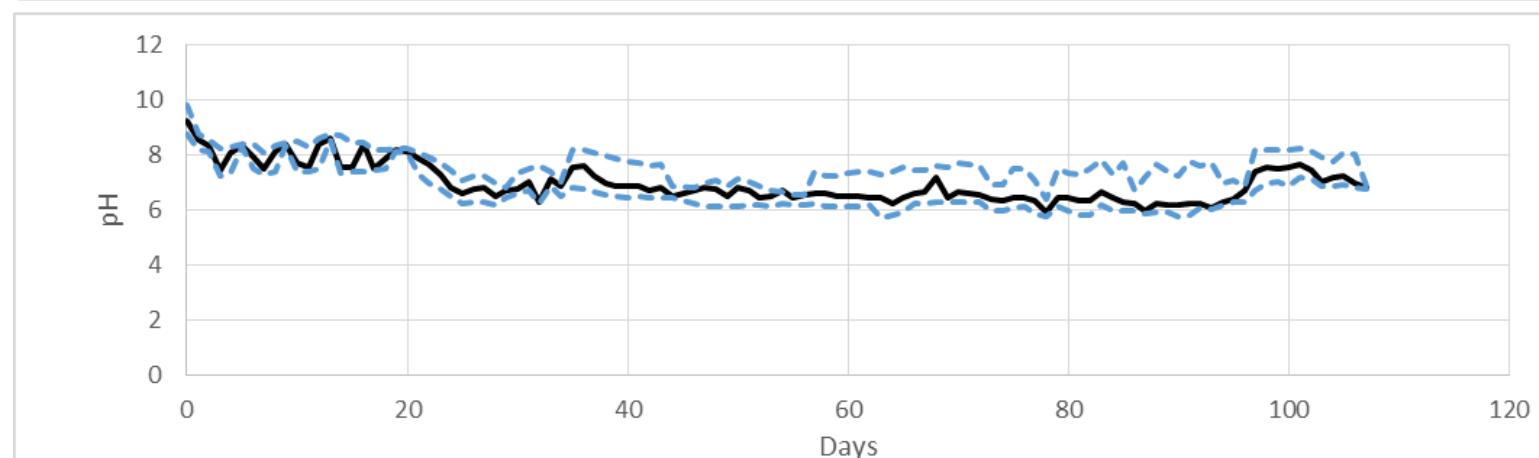


pH:

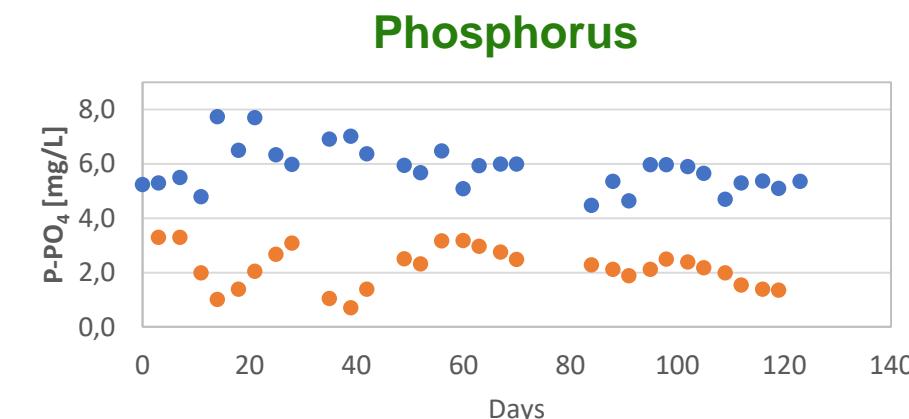
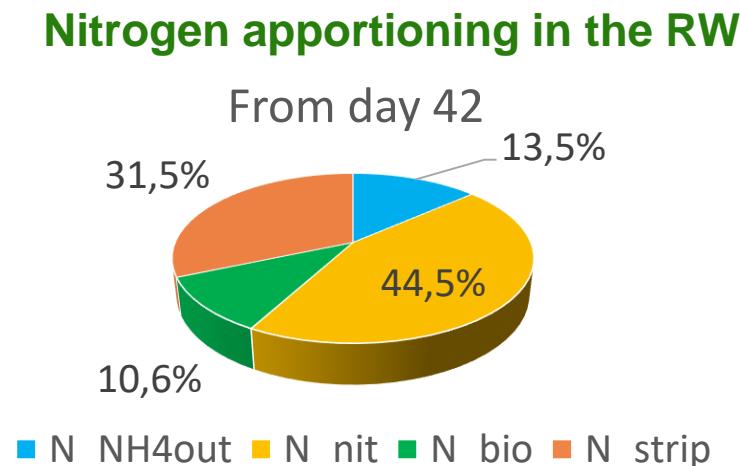
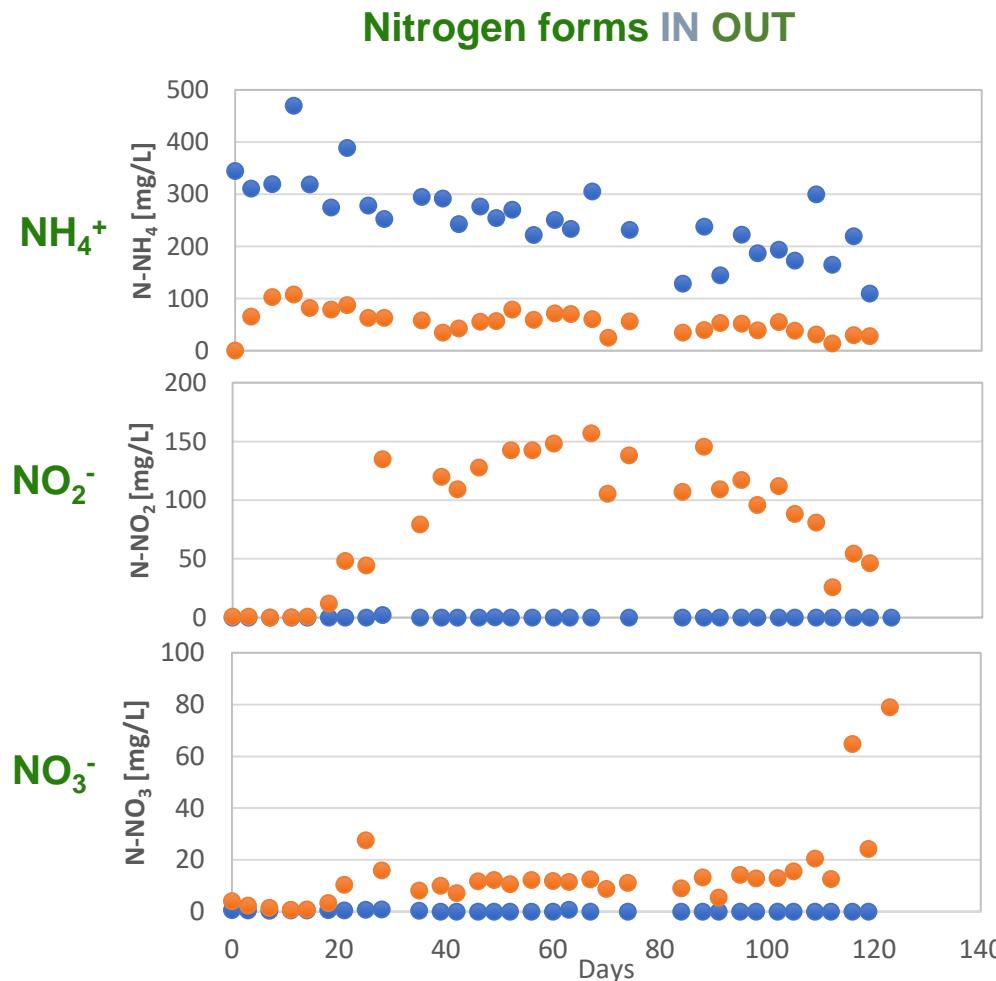
Influenced by:

- Gas bubbling
- Photosynthesis
- Nitrification

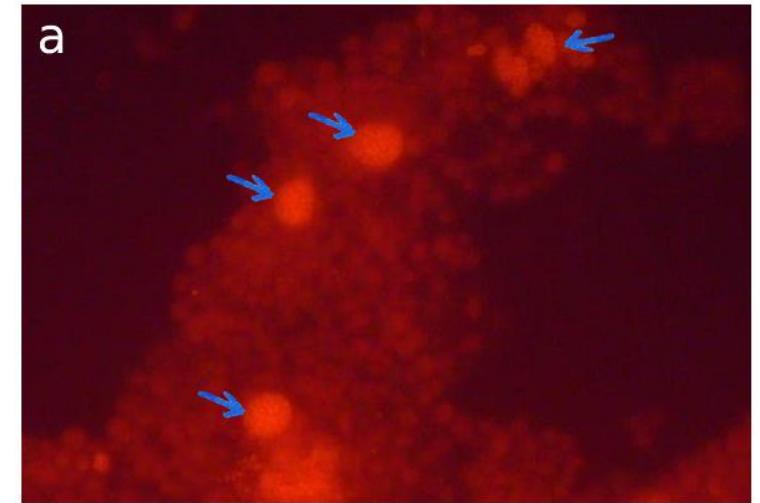
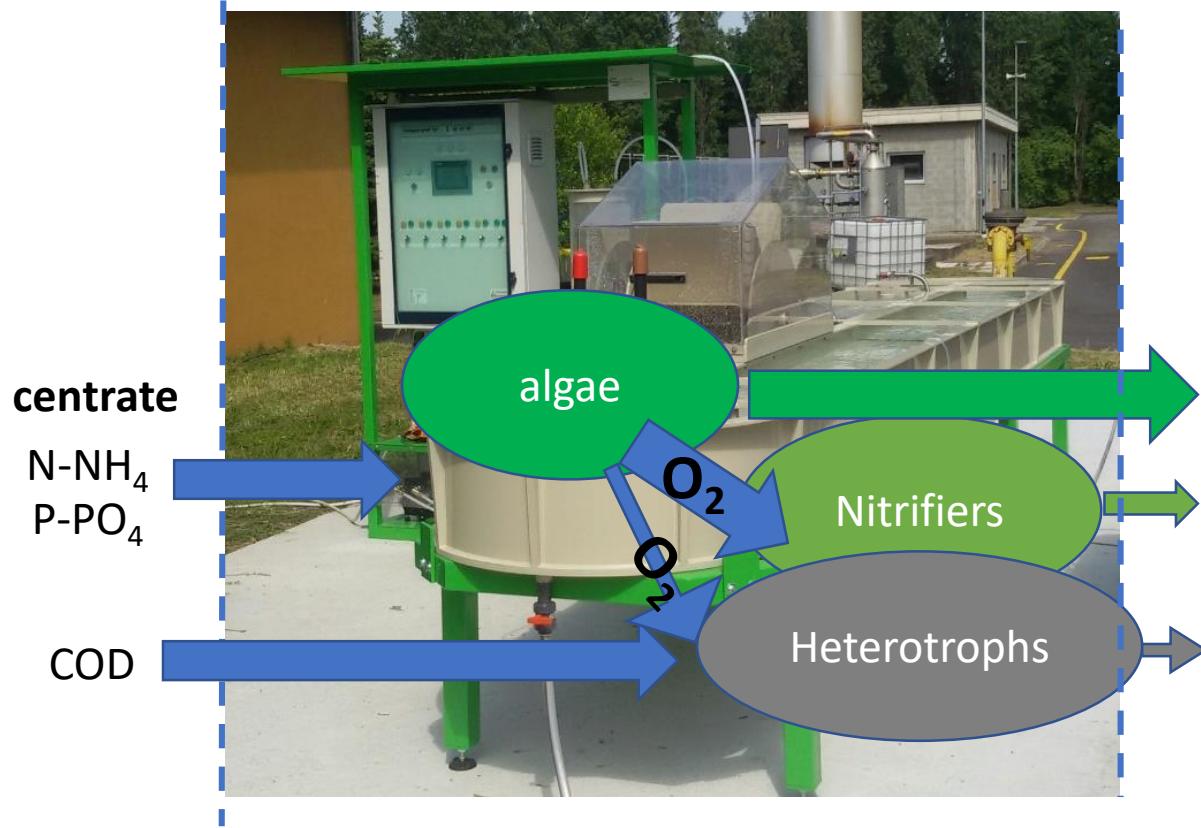
Affects NH₃ stripping!



Results – 2017: N and P fate



Results – 2017: Oxygen balance



AOB + microalgal aggregate with green filter at 40x

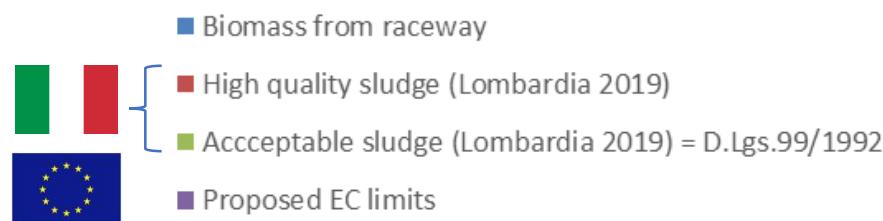
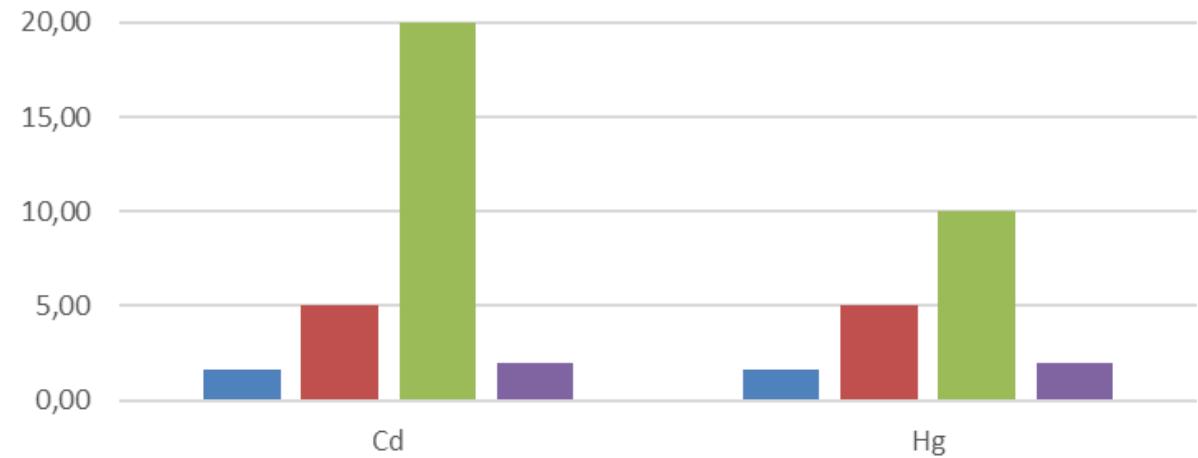
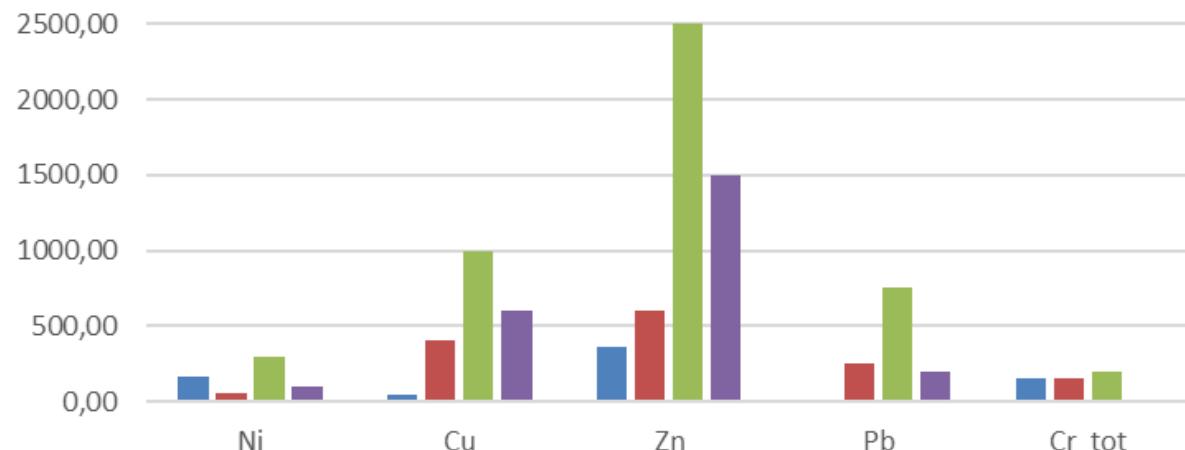
O₂ balance from stoichiometry:

- OPR = oxygen production rate
- OCR = oxygen consumption rate

$$OPR/OCR = 1.2$$

Results – Biomass characteristics

Metal content in algal biomass (mg/kg TSS)



Results – Biomass characteristics

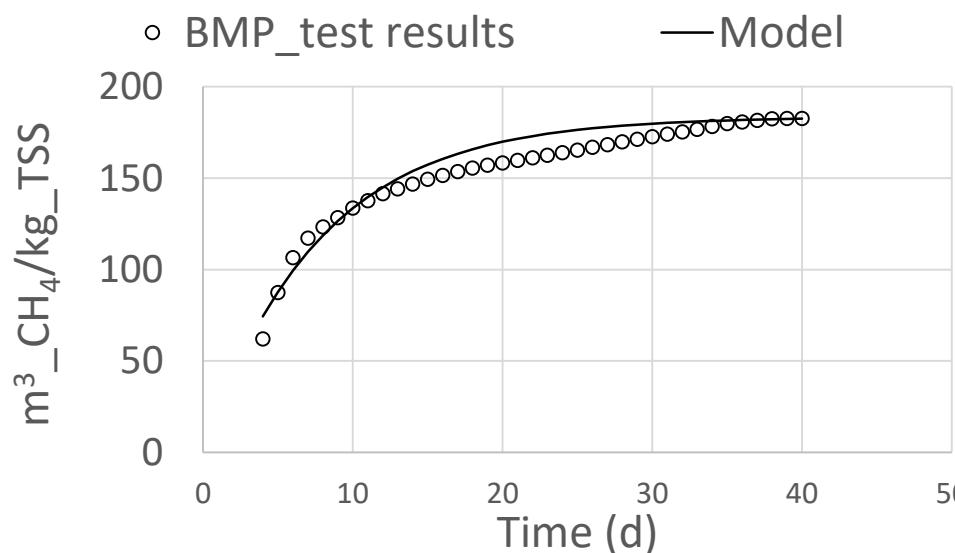
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Elemental analysis (% on TSS): 13 tests

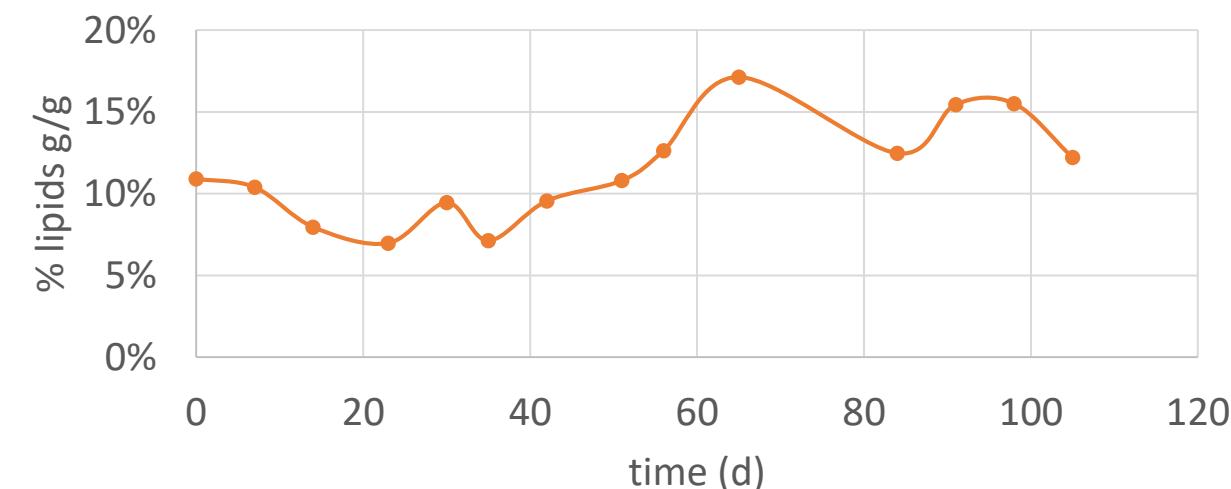
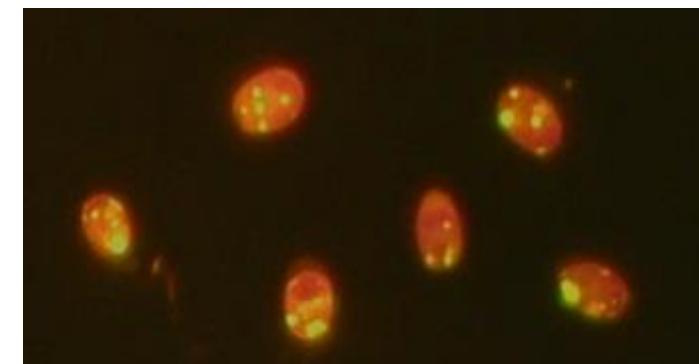
C	43,3 ± 6,9
H	7,4 ± 1,1
N	8,5 ± 1,0
P	0,9 ± 1,9

Methane yield

Batch BMP tests = 180-200 m³ CH₄/kg TSS



Lipid content



Results – 2018: overall results

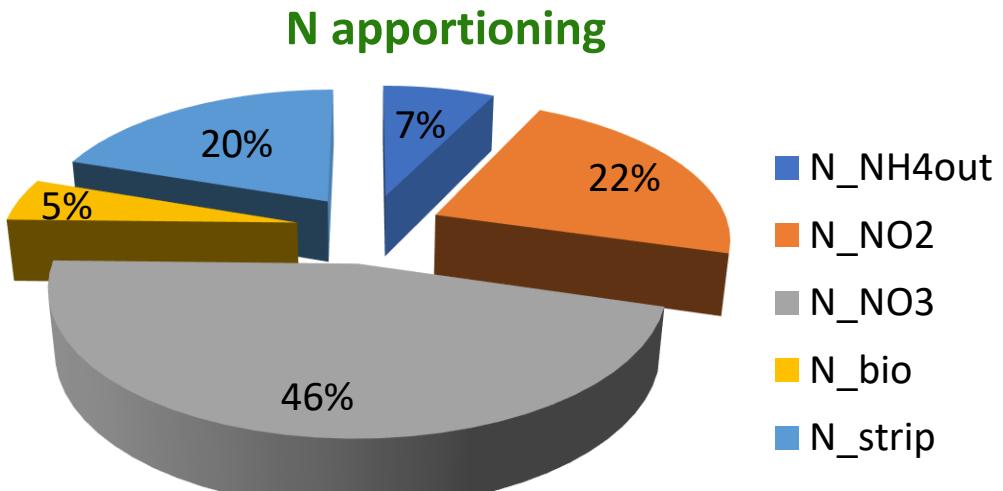
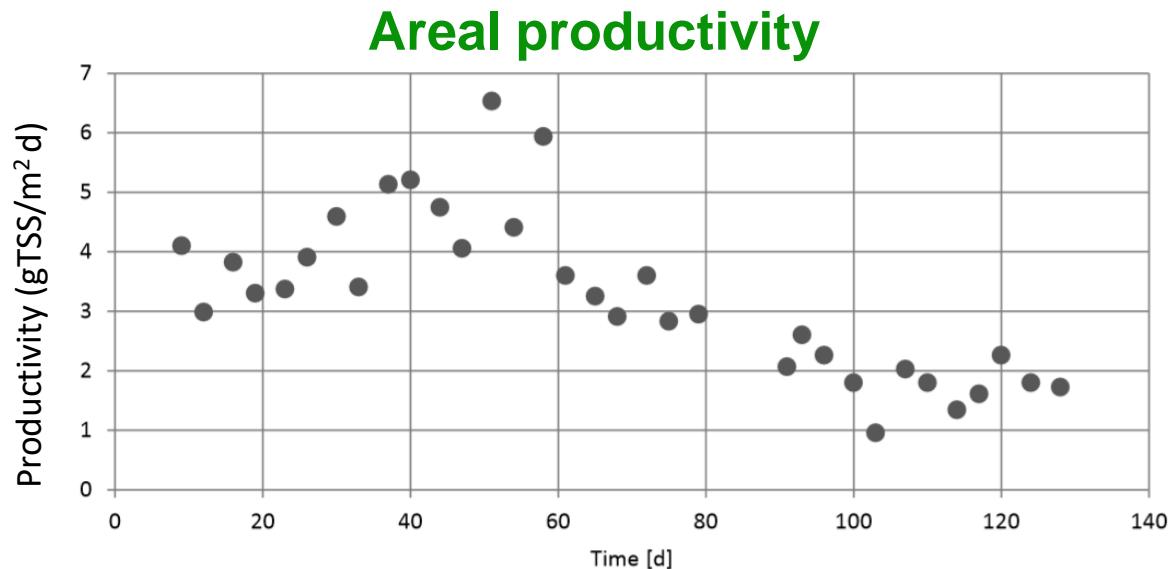
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Second year: 23/5 -5/12/2018



Cover to protect from rain but PAR reduction of 53%

- Reduced productivity compared to 2017
- Constant removal of ammonium:
 - Assimilation ↓
 - Nitrification ↑
 - Stripping ↓
- Lipid content: $5.4 \pm 1.8\%$



Results – 2018: effect on off - gas

Measurements at:

SP1: off-gas

SP2: After pretreatment (Lime from UniCalce)

= IN column

SP3: After transfer column = OUT column

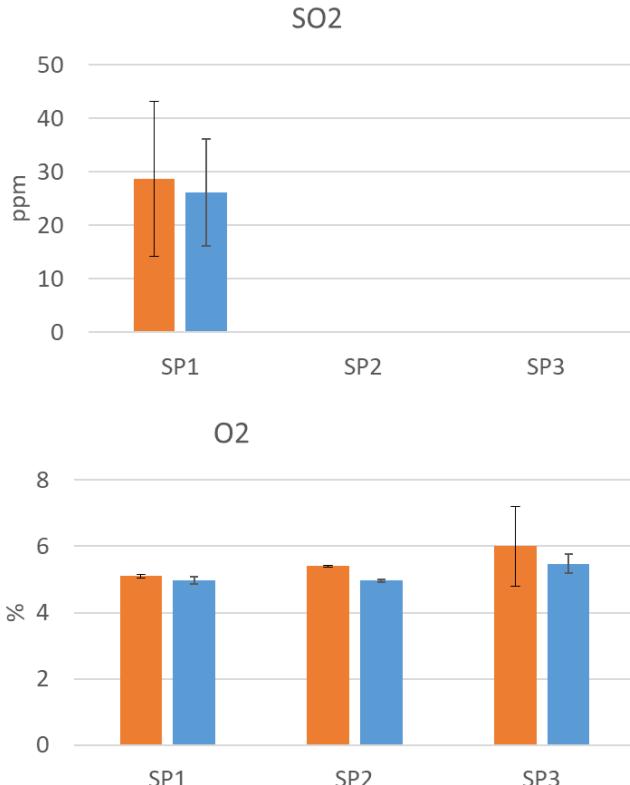
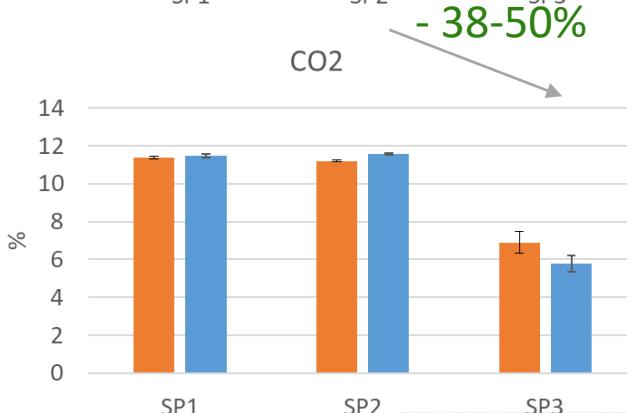
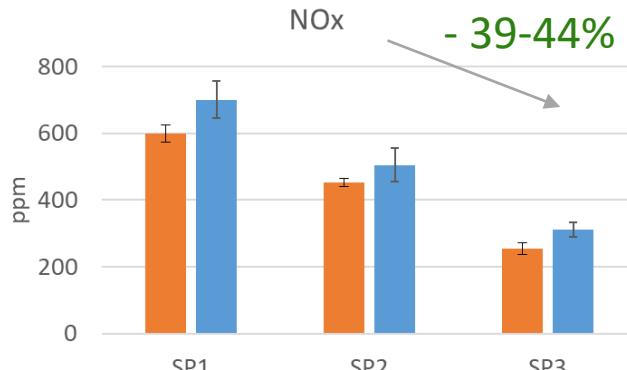
Probe:

MADUR GA-21plus

Sampling: every 15 s for 45 min



Measuring campaigns: 11/10/2018, 19/10/2018

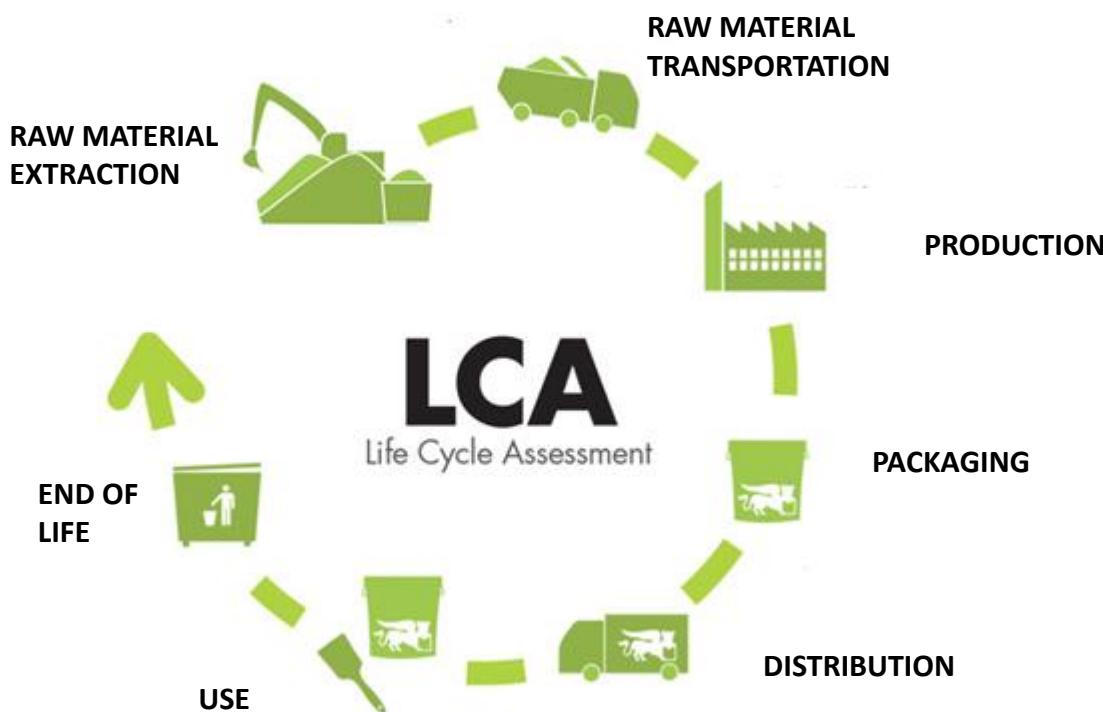


Results – LCA

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Aim:

- Quantify environmental-energy improvements
- Provide indications for a sustainable design of a full-scale plant



12 IMPACT CATEGORIES FROM ILCD METHOD 2011

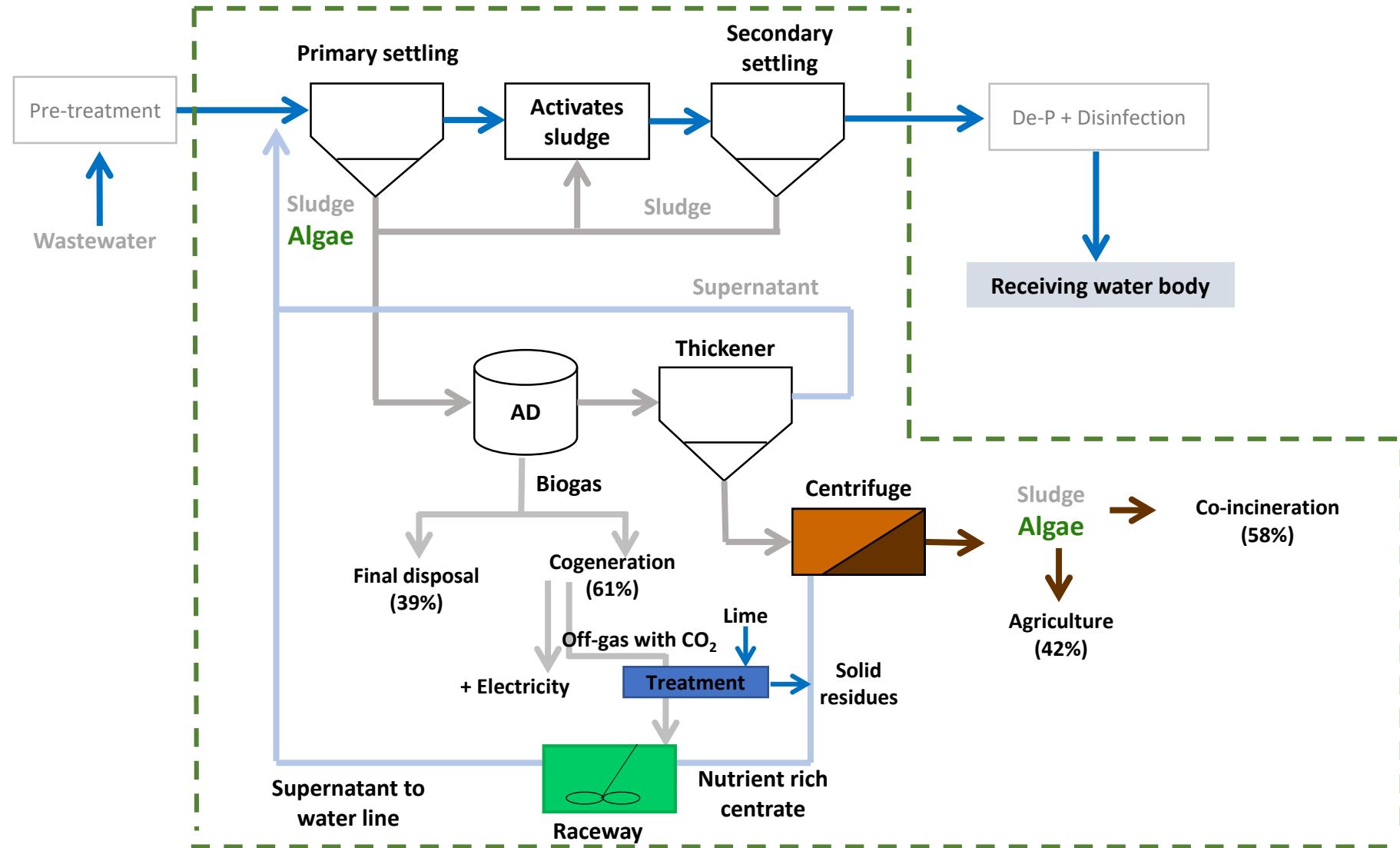
Climate change - CC	kg CO ₂ eq.
Ozone depletion - OD	kg CFC-11 eq.
Human toxicity, non cancer-effects - HT _{NC}	CTUh
Human toxicity, cancer effects - HT _C	CTUh
Particulate matter - PM	kg PM _{2.5} eq.
Photochemical ozone formation - POF	kg NMVOC eq.
Acidification - A	mol H ⁺ eq.
Terrestrial eutrophication - TE	mol N eq.
Freshwater eutrophication - FE	kg P eq.
Marine eutrophication - ME	kg N eq.
Freshwater ecotoxicity – FEC	CTUe
Mineral, fossil & renewable resource depletion – RD	kg Sb eq.

+ 3 ENVIRONMENTAL INDICATORS:

- Cumulative energy demand - CED (MJ)
- Consumption of water resources (m³ water) - WD
- Land consumption (m² per year) - LC

Results – LCA

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Functional unit: Treatment of 1000 m³ of wastewater

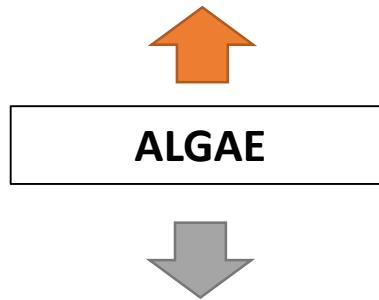
Hypotheses for the raceway:

- Available area: 0.1 m²/PE
- Productivity: 7.8 gTSS/m²/d
- Operation: 275 d/y
- Plant life: 20 years,
- Basins in earth → no use of concrete / asphalt
- Waterproof sealing layer

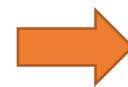
Results – LCA

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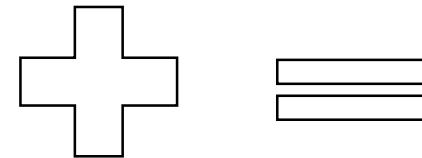
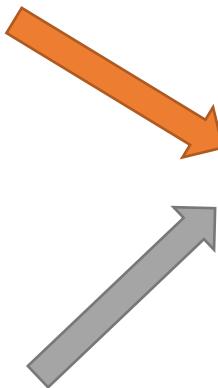
- Raceway building
- Off-gas pretreatment
- Increase of gaseous emissions: CO and NH₃
- Final disposal of algal residues



- Reduction of gaseous emissions: SO₂, NO_x, biogenic CO₂
- Reduction of heavy metal load to the water body
- Electricity savings
- Algae valorization (fertilisers and energy production)



Environmental impacts (positive sign +)



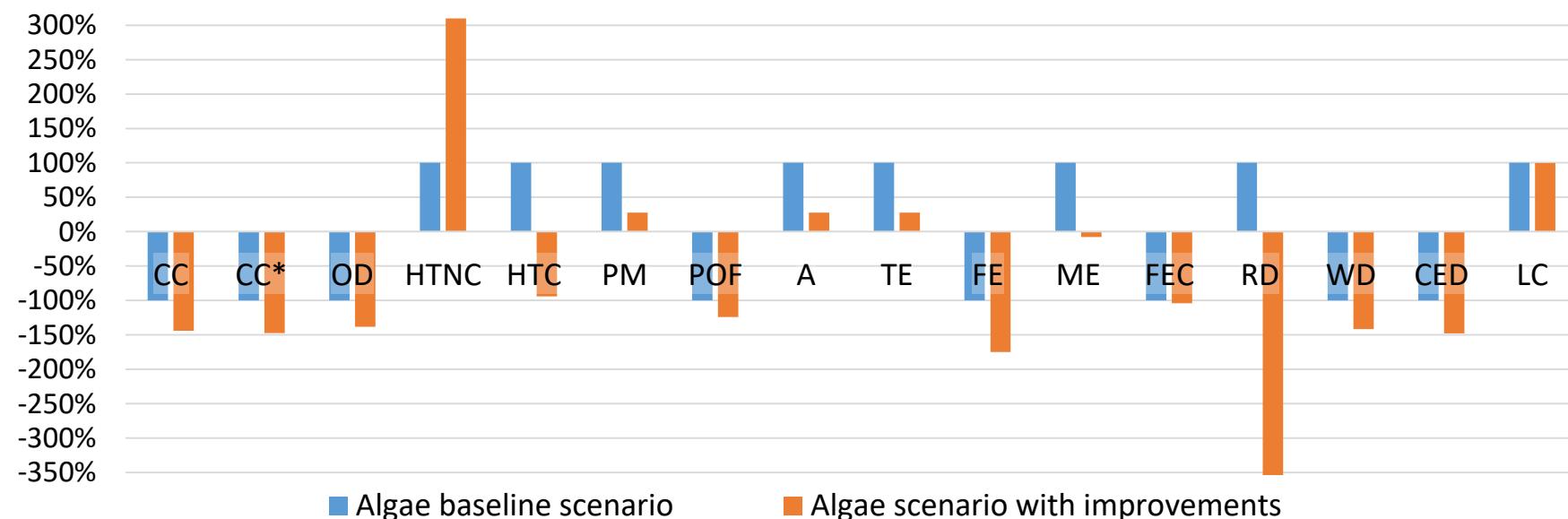
Overall variation with respect to the current wastewater treatment



Environmental benefits (negative sign -)

Alternative scenario

- Hypotheses:
- NH₃ volatilization decrease (more effective pH control): 1/4
 - All residual algae to agriculture
 - Algae productivity improvement: +20%



Improvements in 13 of 16 indicators (all but HT_{NC}, FEC and LC)
Negative sign (improvement) in 11 instead of 8 indicators

Human toxicity, non cancer effects
 Freshwater ecotoxicity
 Land consumption

Results

Economical assessment



Assumptions:

- Area for culturing 0.1 m²/PE
- Experimental productivity*1.2
- Experimental N apportioning
- Experimental value for BMP → Bresso CHP



Cost assumptions

Algae section:

- CAPEX: 160.000 €/ha (algae pond)
- OPEX:
 - 2 W/m³ for paddlewheel
 - Increased costs for centrifuging of digested solids



Energy

Energy saved	W/m ²
• Aeration savings	0.40
• Extra energy from AD	0.179
Energy consumption	
• Paddlewheel	0.150
• Extra costs in sludge line	0.050
Net E saved	
	0.382

Costs

Costs	CAPEX	0.081 €/PE/y
Costs	OPEX	0.019 €/PE/y
Total costs		0.101 €/PE/y
		0.296 €/gTSS
Savings		0.056 €/PE/y
		0.164 €/gTSS



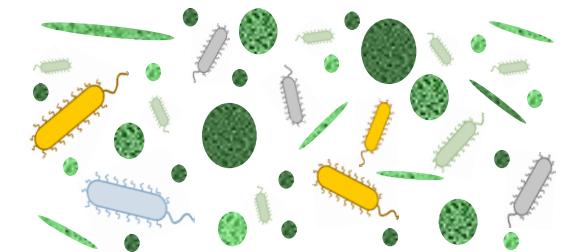
Cost/Saving

1.8

Conclusions and perspectives

Microalgae can grow on digestate, variable productivities (weather conditions)

- ✓ Photo-oxygenation supports nitrifiers, which however compete for P and CO₂
- ✓ Effective ammonium oxidationbut stripping?
- ✓ Energy (as oxygen demand) saving in water line
- ✓ Expected positive LCA with better control of stripping and stabilized productivity (at larger scale)



Algae valorization is crucial to support algae economics:

- No relevant lipid content → no biodiesel
- No great BMP → no biogas
- compatible with agriculture → promising production of high-value bio-stimulants to achieve positive economic assessment
- Bioplastics → Wast4Plast project 1/06/2019 → 1/6/2021



But also...testing the effects of different culturing conditions, as:

- Improving the light exposure
- Optimization of CO₂ supply (CO₂ from biomethane upgrading)
- Two steps algal culturing to get N starvation
- Testing organic carbon supply...

Thanks to:

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Ing. Giulia Borghi
Ing. Camilla Tua

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