



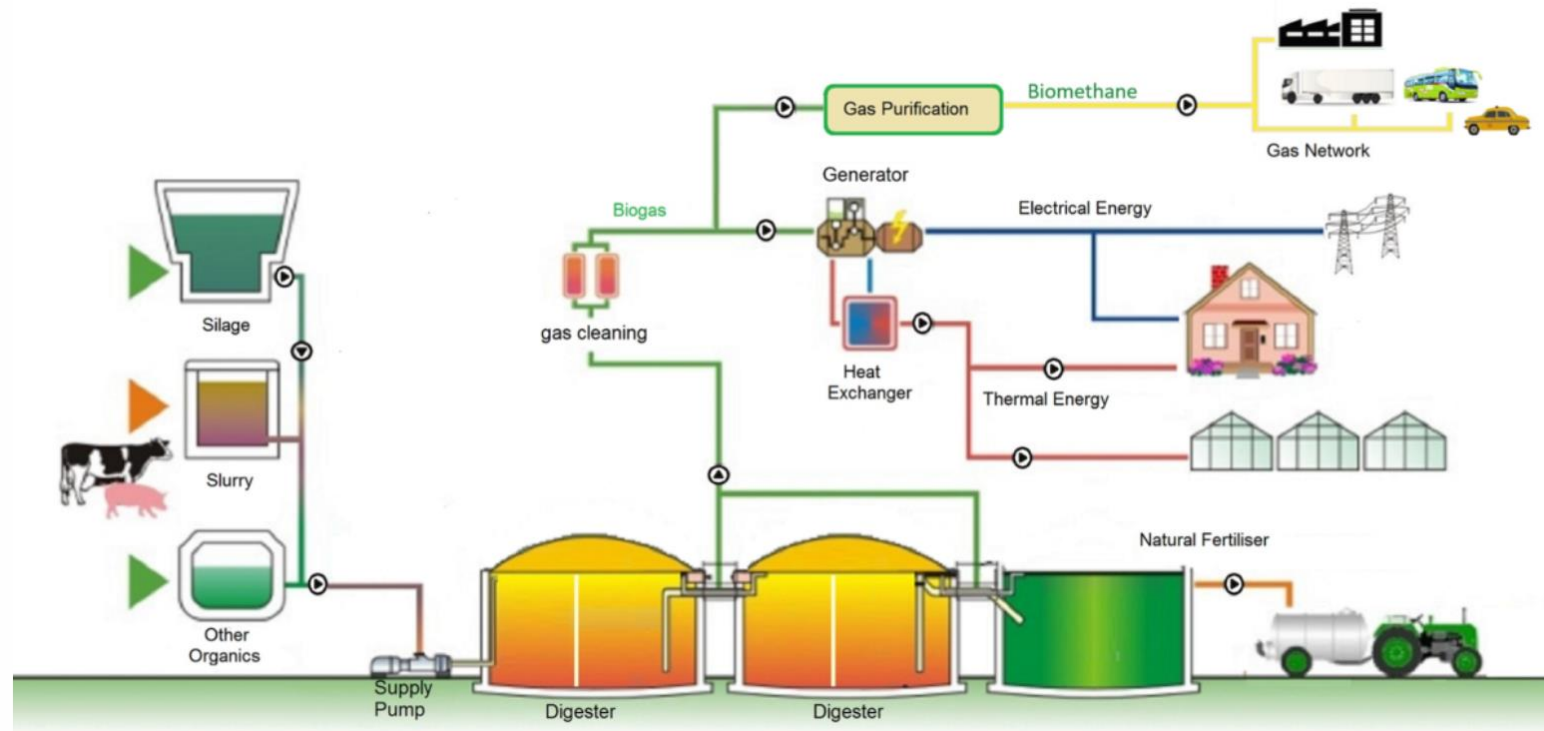
# Technical, environmental, and economic evaluation of semi-continuous anaerobic digestion of pre-treated organic fraction municipal solid waste: effect of the organic loading rate on process performance

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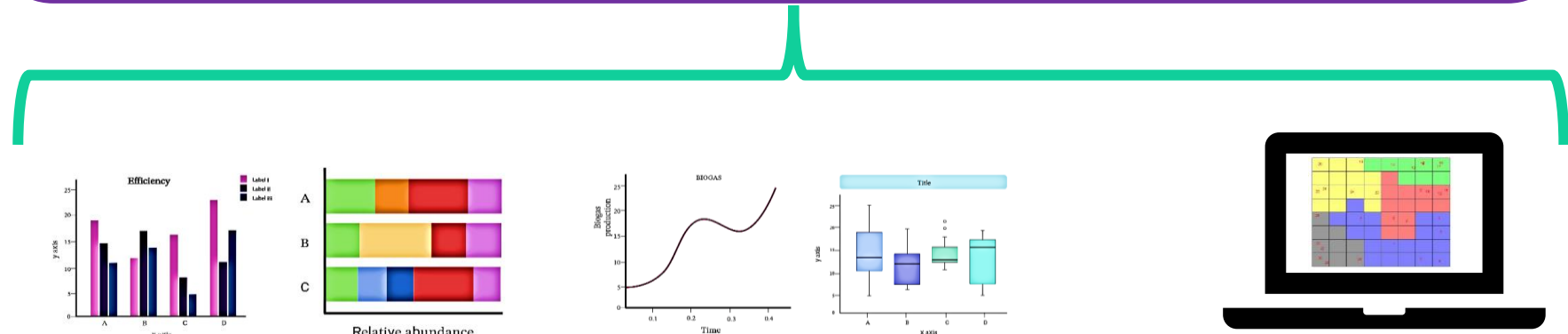
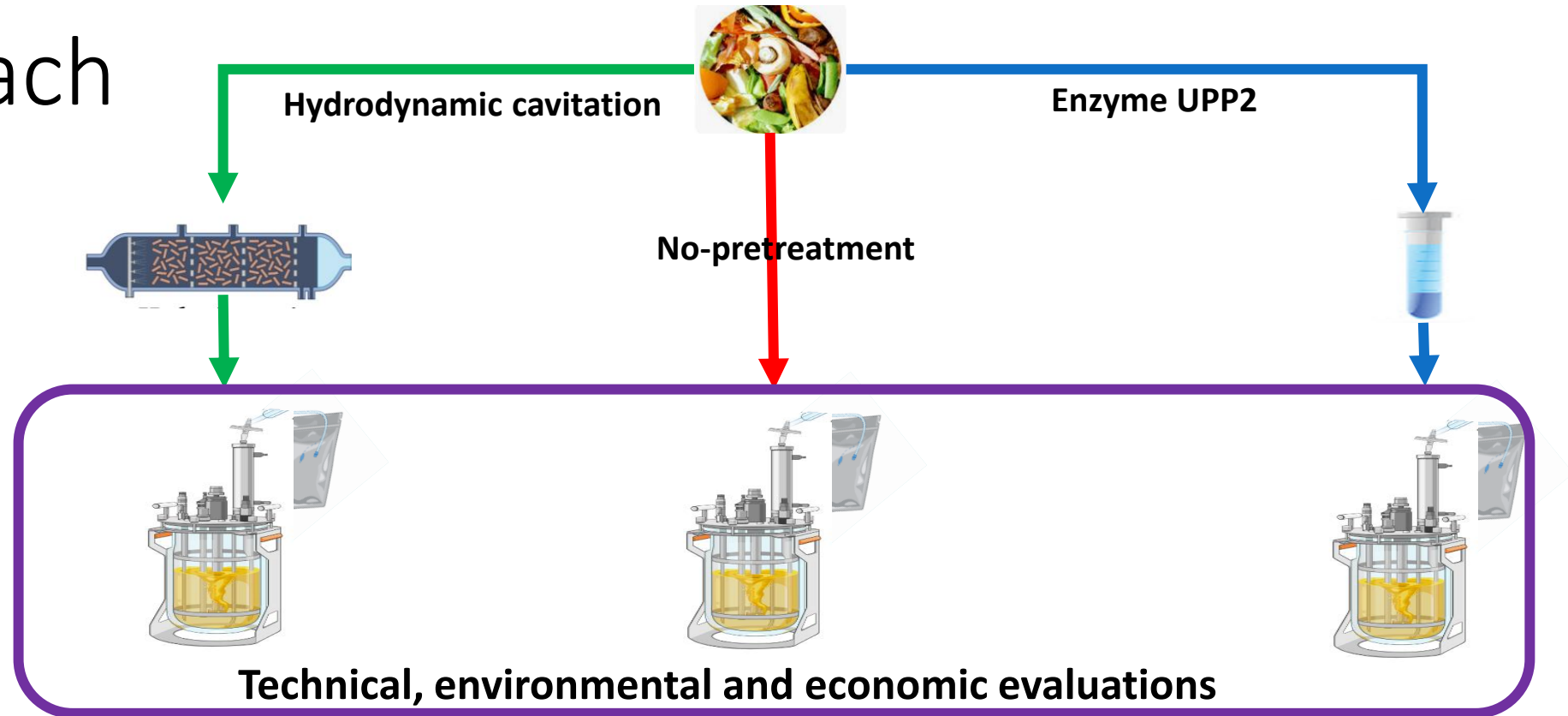
# Introduction to anaerobic digestion



$$\text{OLR} \left( \frac{\text{kg vs}}{\text{m}^3 \text{ d}} \right) = \frac{\text{Feed flow rate} \left( \frac{\text{m}^3}{\text{d}} \right) \cdot \text{substrate concentration} \left( \frac{\text{kg vs}}{\text{m}^3} \right)}{\text{Volume of the reactor} (\text{m}^3) \cdot \text{time} (\text{d})}$$

$$\text{HRT} (\text{d}) = \frac{\text{Volume of the reactor} (\text{m}^3)}{\text{Feed flow rate} \left( \frac{\text{m}^3}{\text{d}} \right)}$$

# Our approach



# Pre-treatment conditions

## Hydrodynamic cavitation

T = 55°C

time = 10 min



## Enzymatic pre-treatment

Enzyme: UltraPract® P2 (UPP2)

Composition = mix of cellulases, hemicelluloses, pectinases, and protease

Dose = 1 mL/g TS

pH = 6.5

T = 30 °C

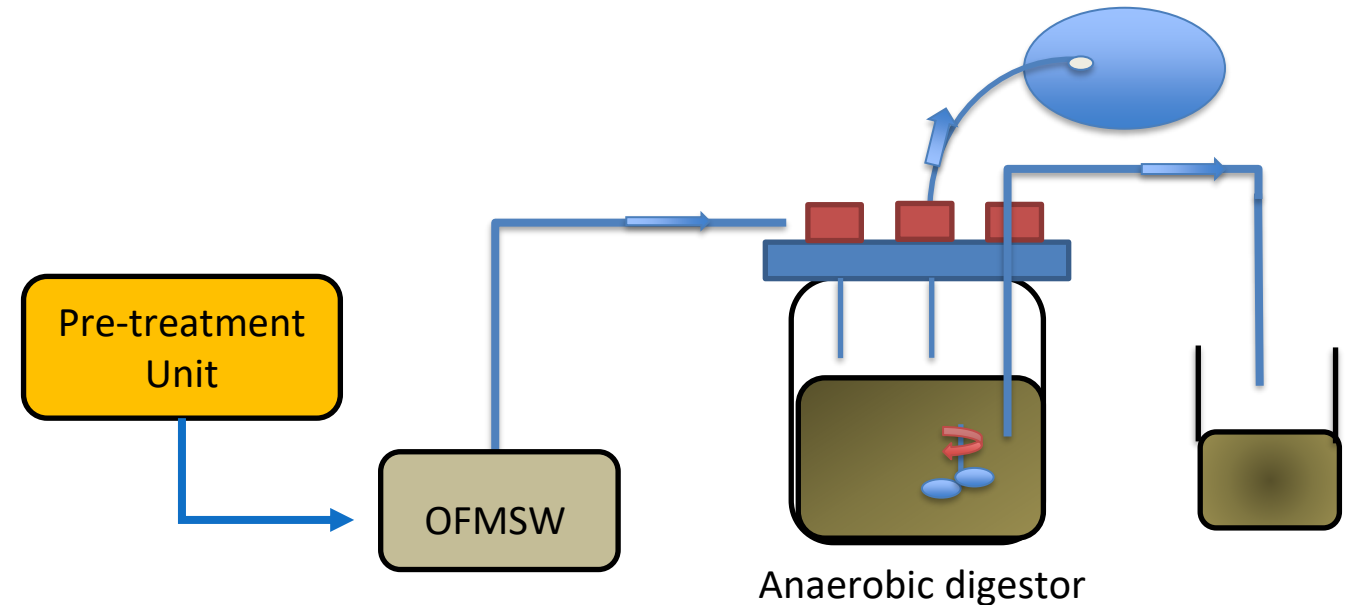
Time = 120 min



<https://www.biopract-abt.de/it/prodotti/ultrapract-p2>

# Anaerobic digestion conditions

- Semi-continuous feed mode
- Total solid (TS) (%) feed: 6 %
- Substrate (S): organic fraction municipal solid waste (OFMSW) from San Carlo S.p.A. (Fossano, Italy)
- Inoculum (I): digestate coming from cow-agricultural waste
- $T = 37\text{ }^{\circ}\text{C}$
- Volume = 1 L



# Anaerobic digestion conditions

Variation of hydraulic retention time (HRT)

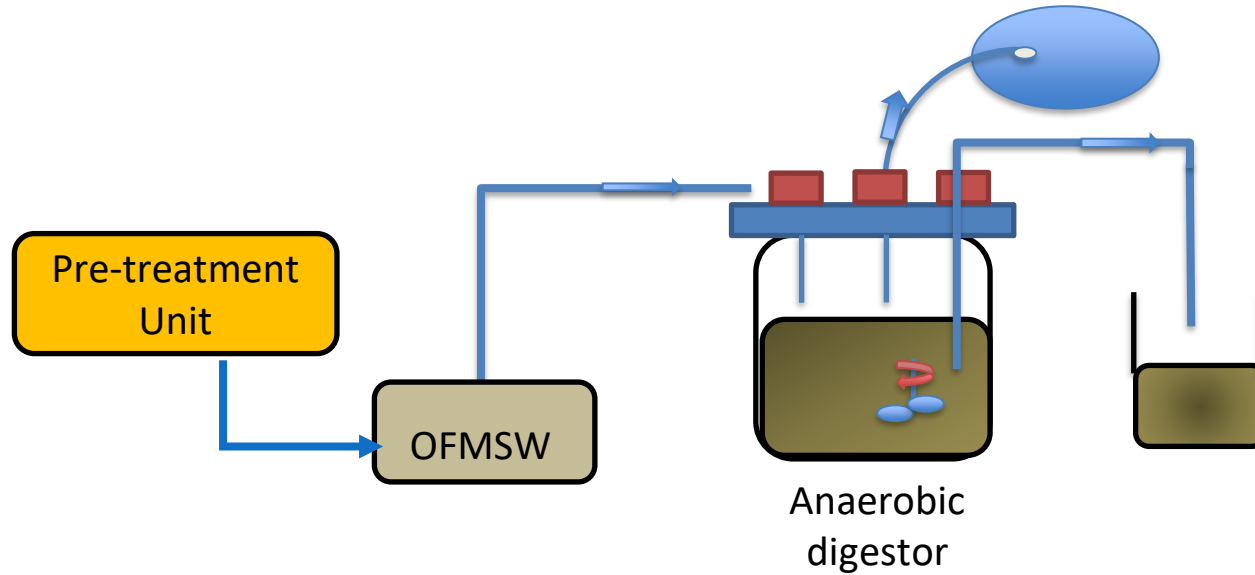
HRT = 16 d → OLR = 3.38 kg vs/m<sup>3</sup> d

HRT = 14 d → OLR = 3.87 kg vs/m<sup>3</sup> d

HRT = 12 d → OLR = 4.50 kg vs/m<sup>3</sup> d

HRT = 10 d → OLR = 5.40 kg vs/m<sup>3</sup> d

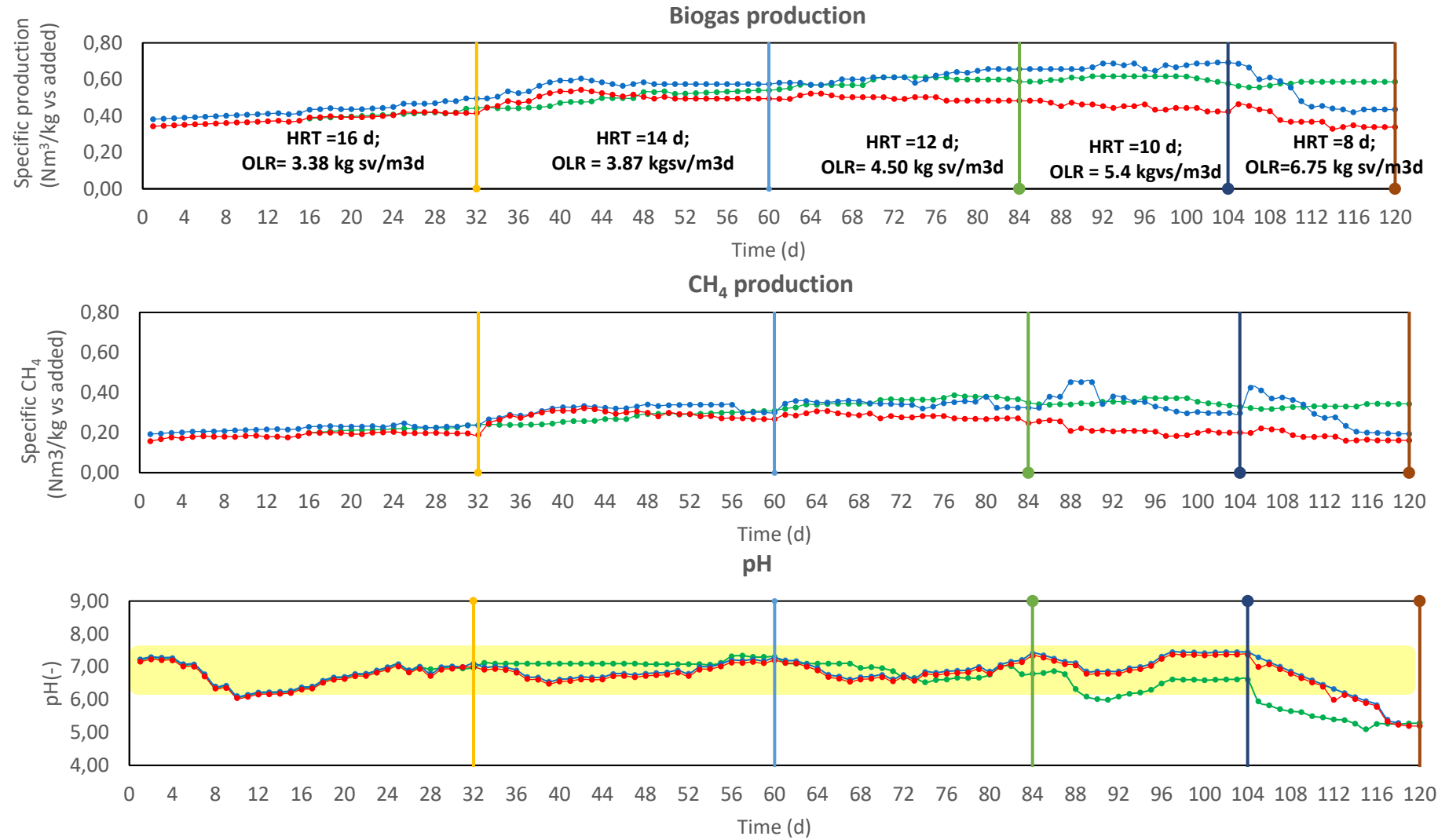
HRT = 8d → OLR = 6.75 kg vs/m<sup>3</sup> d



	OFMSW		Inoculum CAS	
	mean	dev.st	mean	dev.st
TS (%)	19	2.3	6	0.1
VS/TS (%)	97	1.8	67.9	1
C (%)	45.7	2.7	40.6	0.6
H (%)	6.1	0.3	3	0
N (%)	2.4	0.2	7.9	0.1
S (%)	0.2	0.1	0	0
O /%	45.4	3.1	48.5	2.1
pH	5.3	0.2	7.7	0.1



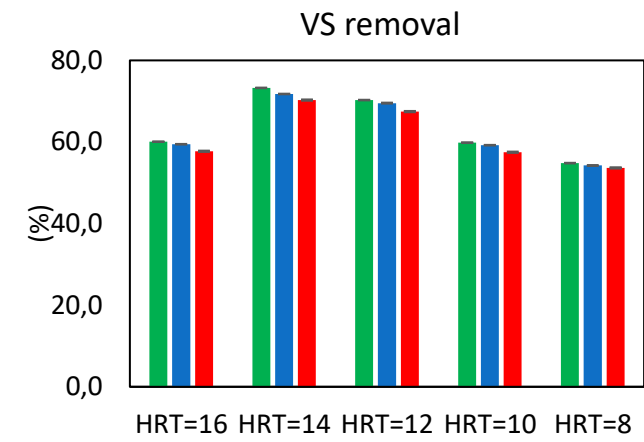
# Anaerobic digestion performances



HC\_OFMSW

EN\_OFMSW

OFMSW



Introduction

Technical evaluation

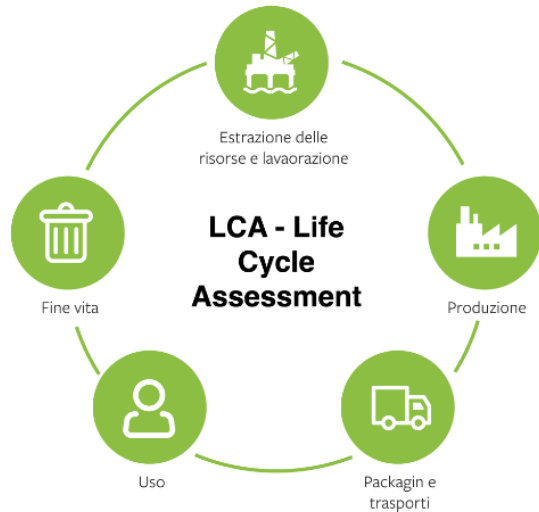
Environmental evaluation

Economic evaluation

Data analysis

Conclusions

# Environmental evaluation



- **Goal and scope:** comparison of the environmental impact of the three AD configurations
- From grave to cradle
- FU= 1 MWh of produced energy
- Method: ReCiPe MidPoint (H)
- Method: cumulative energy demand (CED)

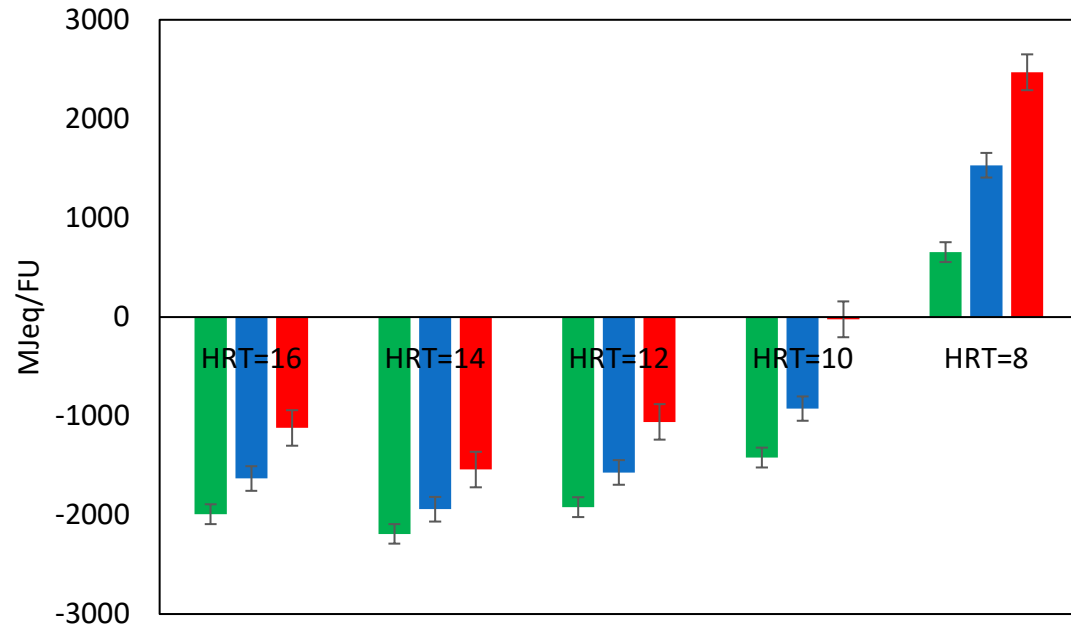
Database Ecoinvent 3.9.1

Software: Sima Pro 9.5

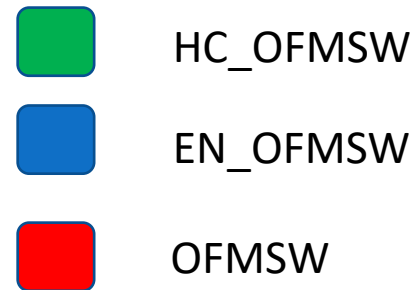
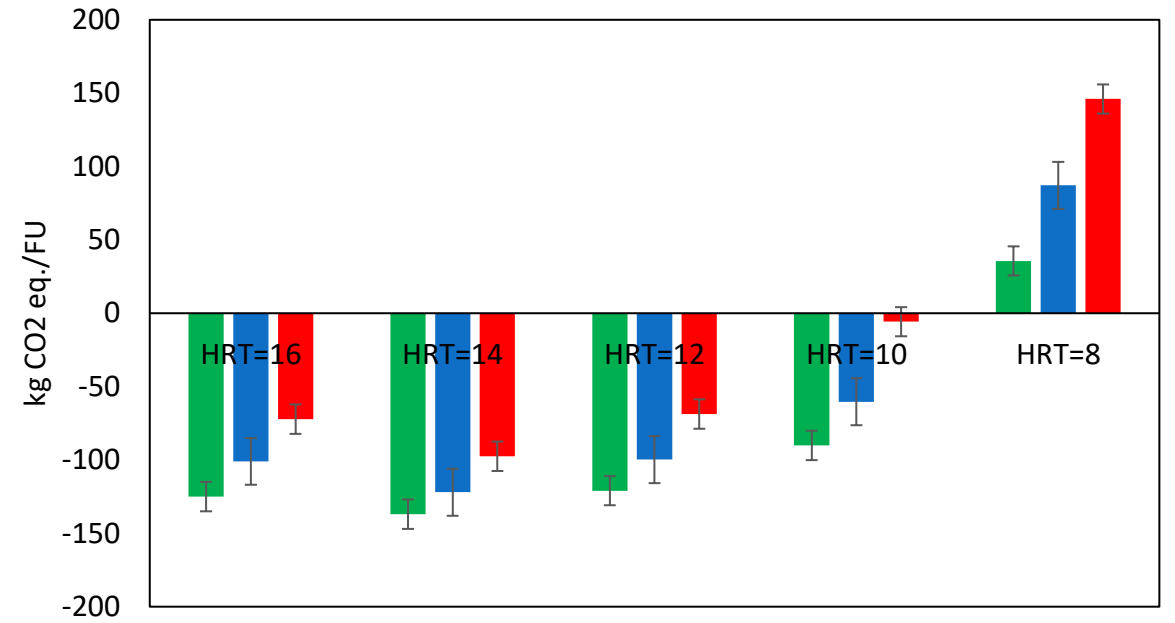


# Environmental performances

## CED



## Global warming potential



# Economic evaluation

$C_0$  was defined with Guthrie method

## Amortisation

$$A = C_0 \frac{i \cdot (1 + i)^n}{(1 + i)^n - 1}$$

**Revenues** = Biogas sale –  $C_0$  - operative costs

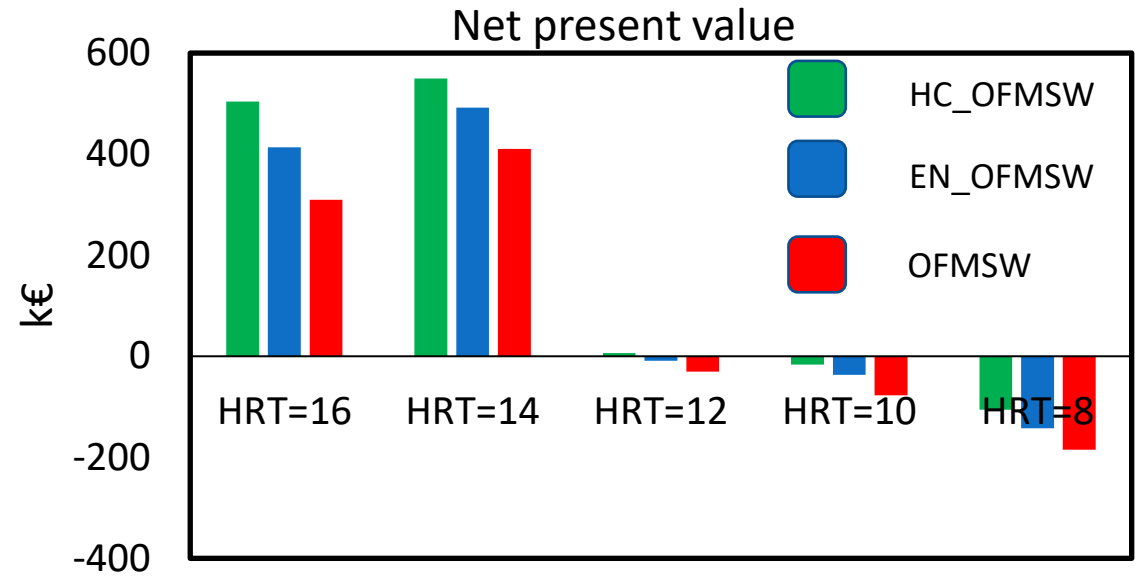
## Net present value

$$NPV = \sum_{t=1}^T \frac{C_t}{(1 + d)^t} - C_0$$

## Payback time

$$PBT = \frac{\text{Investimnet costs}}{\text{Annual cash inflow}}$$

Plant life = 20 y



## Payback time

	HC_OFMSW	E_OFMSW	AD_OFMSW
HRT=16	4	4	4
HRT=14	4	4	4
HRT=12	18	>20	>20
HRT=10	>20	>20	>20
HRT=8	>20	>20	>20

# Principal components analysis

PCA applied on data set **sample x variables =30 x 9**:

Data were autoscaled

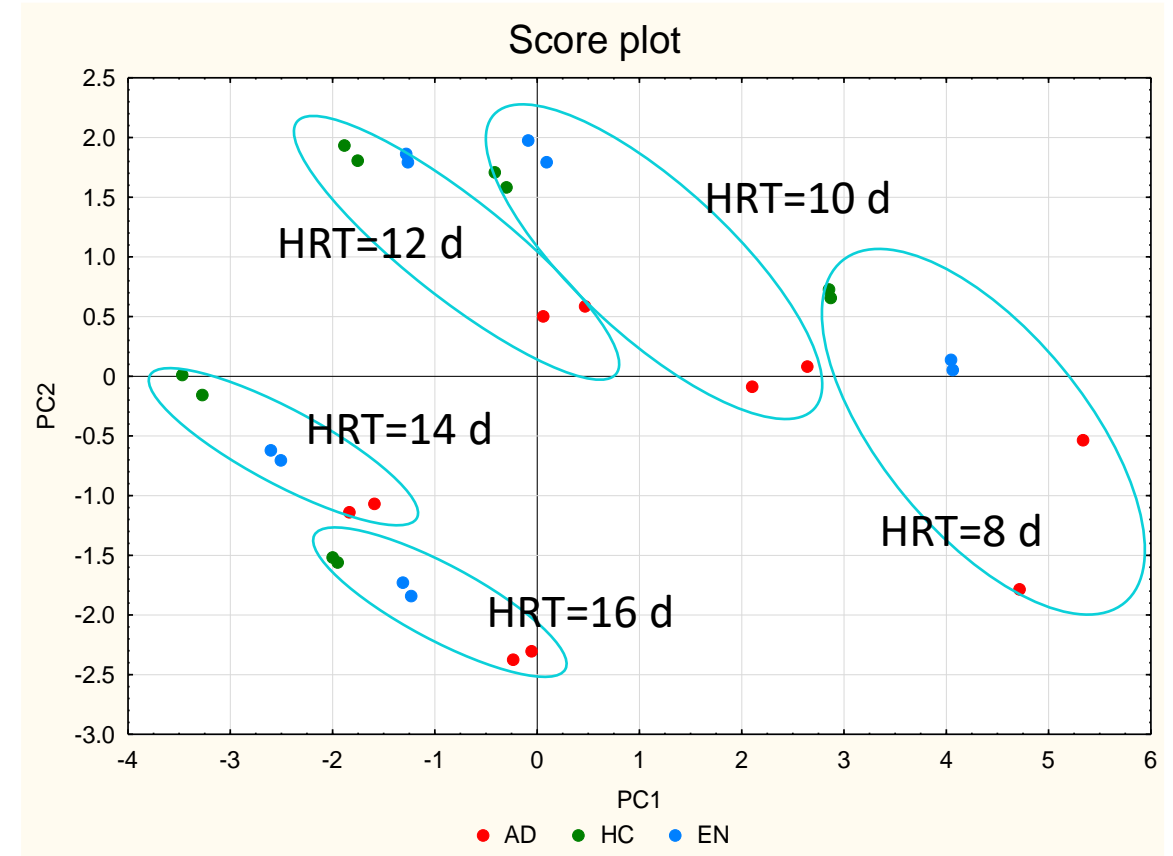
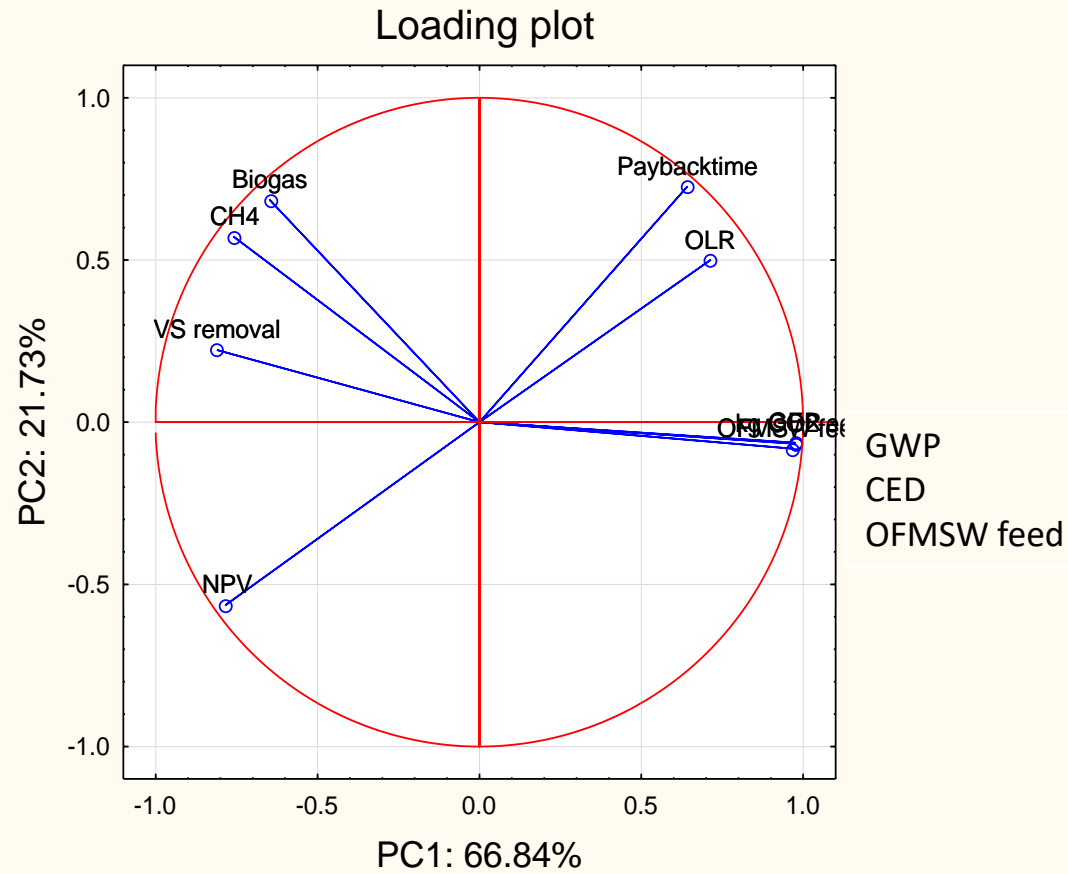
- Samples = 30 =5 HRT x 3 AD configurations x 2 replicates
  - HRT = 16, 14, 12, 10, 8
  - AD configurations: HC, EN, non pre-treated OFMSW
  - Tested in duplicates
- Variables = 9
  - OFMSW feed;
  - CED
  - NPV
  - Biogas;
  - Kg CO<sub>2</sub> eq
  - Payback time
  - CH<sub>4</sub>;
  - OLR;
  - VS removal;

	% Total - variance	Cumulative - %
PC1	66.84	66.84
PC2	21.73	88.57
PC3	4.09	92.66
PC4	3.50	96.16
PC5	2.54	98.69
PC6	1.18	99.87
PC7	0.11	99.98
PC8	0.01	100.00

\*Elaboration performed with Matlab

# Principal components analysis: score plots

Information about pre-treatments.



# Conclusions

- ❖ The effect of the variations of hydraulic retention time (HRT) and organic loading rate (OLR) was analysed by combining technical, environmental, and economic results in a principal components analysis
- ❖ Decreasing the HRT, the environmental and economic impacts increased.
- ❖ The PCA proved that for HRT = 16 and 14 d, all the AD configurations were high performance, but the non-pretreated reached higher economic advantages than HC and EN.
- ❖ The PCA proved that for HRT = 12-8 d the pre-treatments, especially HC, can better counterbalance the inhibitory effect rather than AD.

Thank you for  
the attention

