Integrated anaerobic digestion and pyrolysis of organic fraction municipal solid waste

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Organic Fraction Municipal Solid Waste (OFMSW)

In EU28 the production of organic fraction of municipal solid waste (OFMSW) is 65-75 % of the total organic waste produced, which means around 88-103 Mt/y of OFMSW.

Composting

Incineration

Mechanical biological treatment

Anaerobic digestion (AD)

EU28:
OFMSW: 300 kg p.c/y

From problem to resource

BIOENPRO4TO – SMART SOLUTIONS FOR SMART COMMUNITIES:
Bio-energy and sustainable product for Green Chemistry (output) through integrated valorisation of urban and industrial waste and biomass (input)

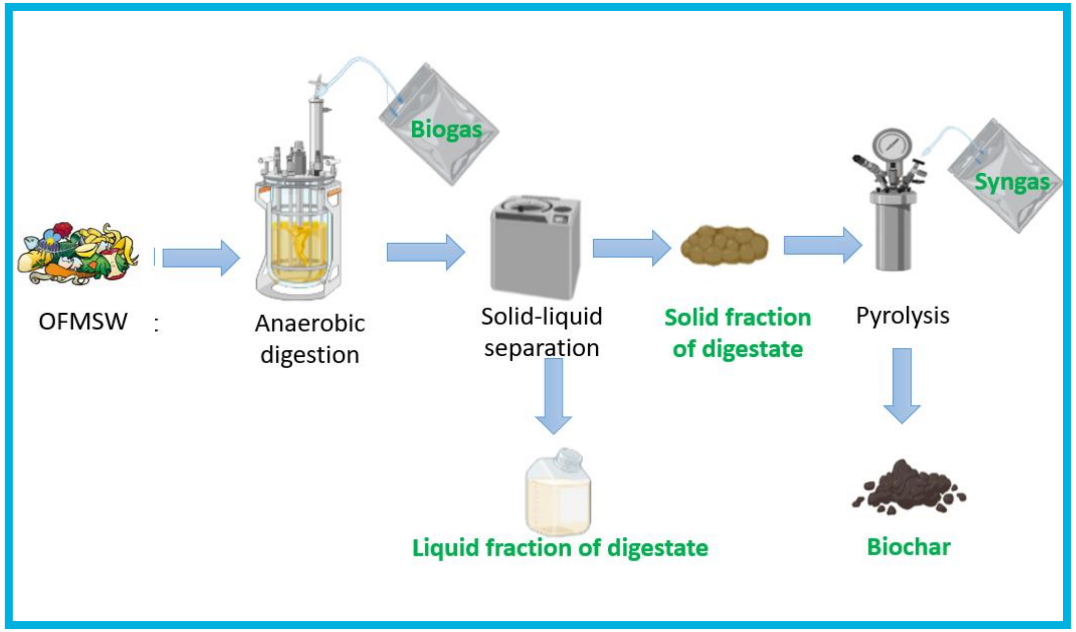
Anaerobic Digestion → **Digestate** → **Pyrolysis**

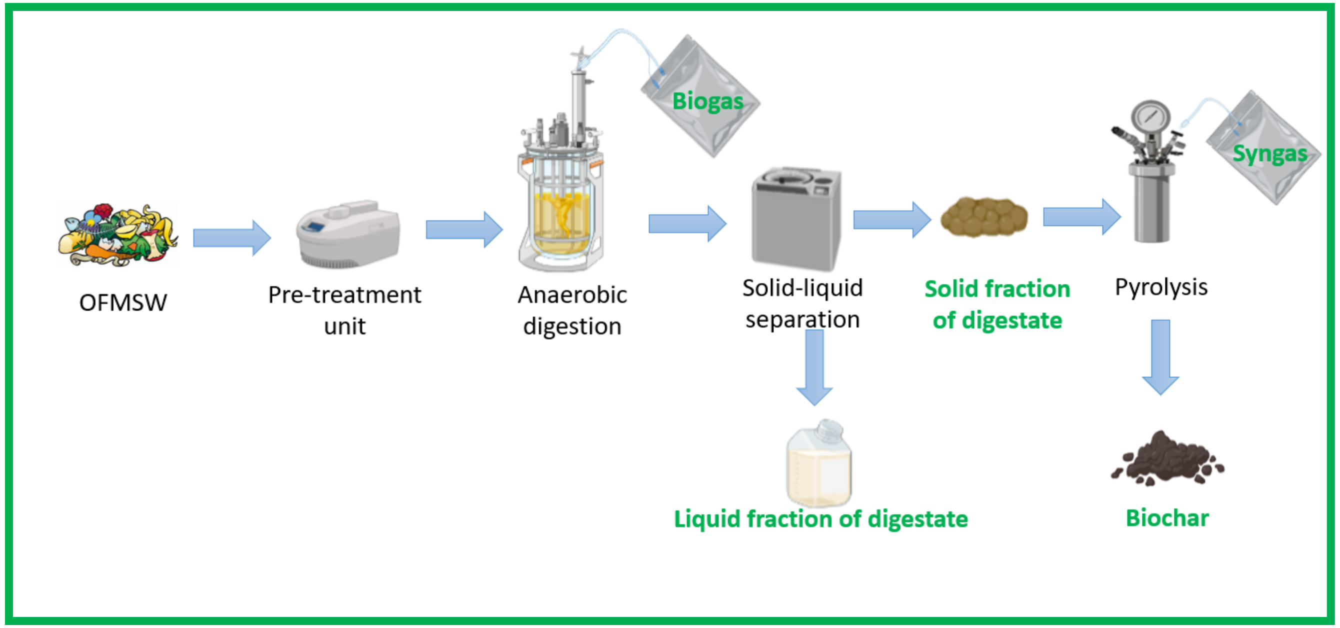
Anaerobic Digestion → **Biogas**

Pyrolysis → **Biochar**, **Bio-oil**, **Syngas**

The aim of the work

Sequential and integrated valorisation of **OFMSW** through **AD** for **biogas** production and **biochar** production through **slow pyrolys of digestate**





Scenario 1:
Sequential anaerobic digestion and slow pyrolys

Scenario 2:
Sequential physical pre-treatment + anaerobic digestion and slow pyrolys

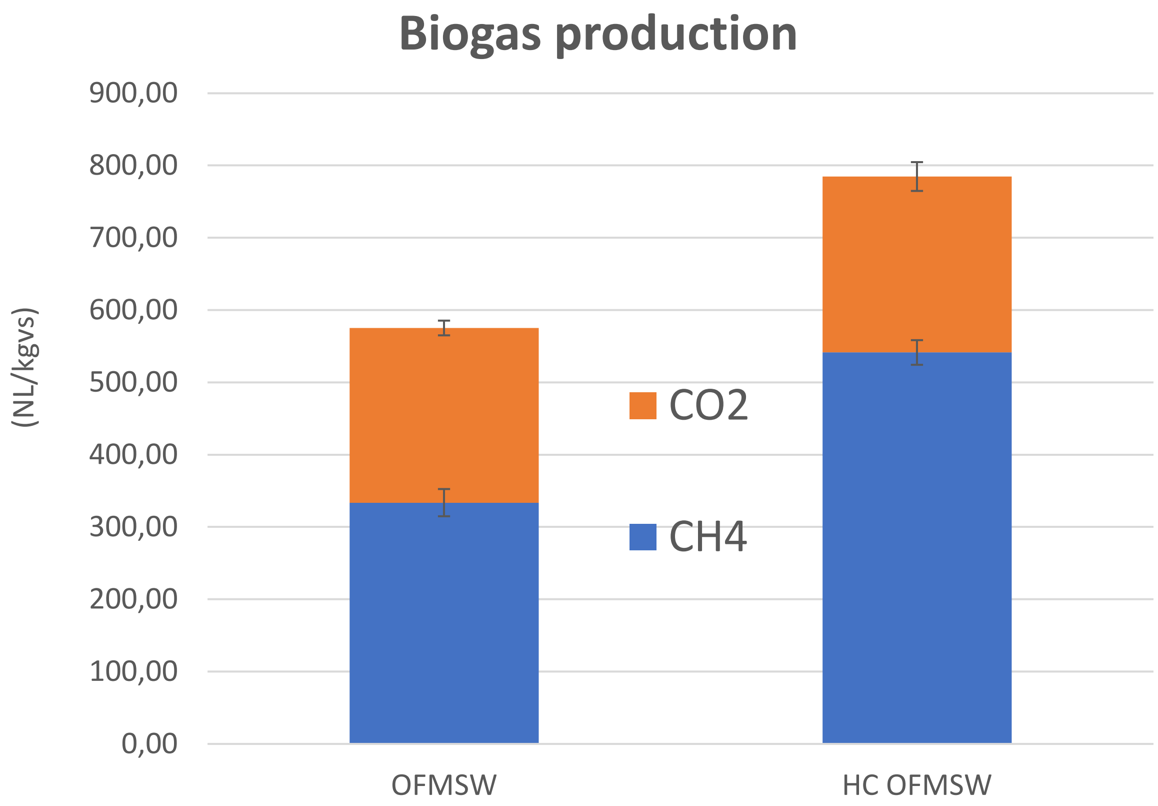
Environmental evaluation

Anaerobic digestion

- Substrate: OFMSW from San Carlo S.p.A. Fossano, Italy
- Batch feeding mode
- Mesophilic process: T =37 °C
- Wet AD: TS= 6%
- Inoculum = digestate of cow agricoltural sludge (CAS) from Fossano Italy incubated for 10 d
- Substrate: Inoculum = 2:1
- Pre-treatment : Hydrodynamic cavitation (HC) at 55°C for 10 min
- Tests in duplicate

	OFMSW		CAS	
	mean	dev.st	mean	dev.st
Water content (%)	89	2,3	94	0,1
TS (%)	11	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



	Scenario I		Scenario II	
	mean	dev.st	mean	dev.st
TS (%)	5,7	0,99	6,002	1,002
VS/TS (%)	52	2,76	46,41	3,4
C (%)	39,34	1,34	34,7	2
H (%)	6,08	2,1	6,23	1,09
N (%)	3,4	0,45	5,6	0,78
S (%)	1,45	0,01	1,39	0,07
O /%)	49,73		0,46	
pH	6,9	0,15	7,56	0,98

Bilancio C:
94.6 %

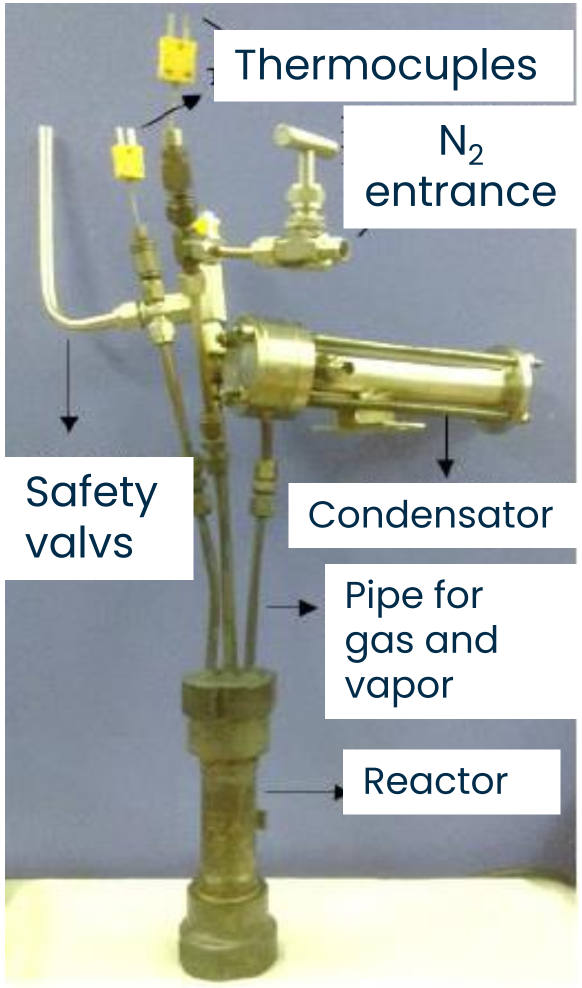
Bilancio C:
99.1 %

Scenario 1:
Sequential anaerobic digestion and slow pyrolys

Scenario 2:
Sequential physical pre-treatment + anaerobic digestion and slow pyrolys

Slow pyrolysis

The target of pyrolysis is the production of **biochar for soil application**.



- Substrate: digestate from Scenario and Scenario II.
- Fixed bed reactor:
- Set temperature:
  - 400 °C;
  - 500 °C;
  - 600 °C.

According to thermogravimetric analysys

- Heating rate:
  - 5,
  - 10,
  - 15 °C/min

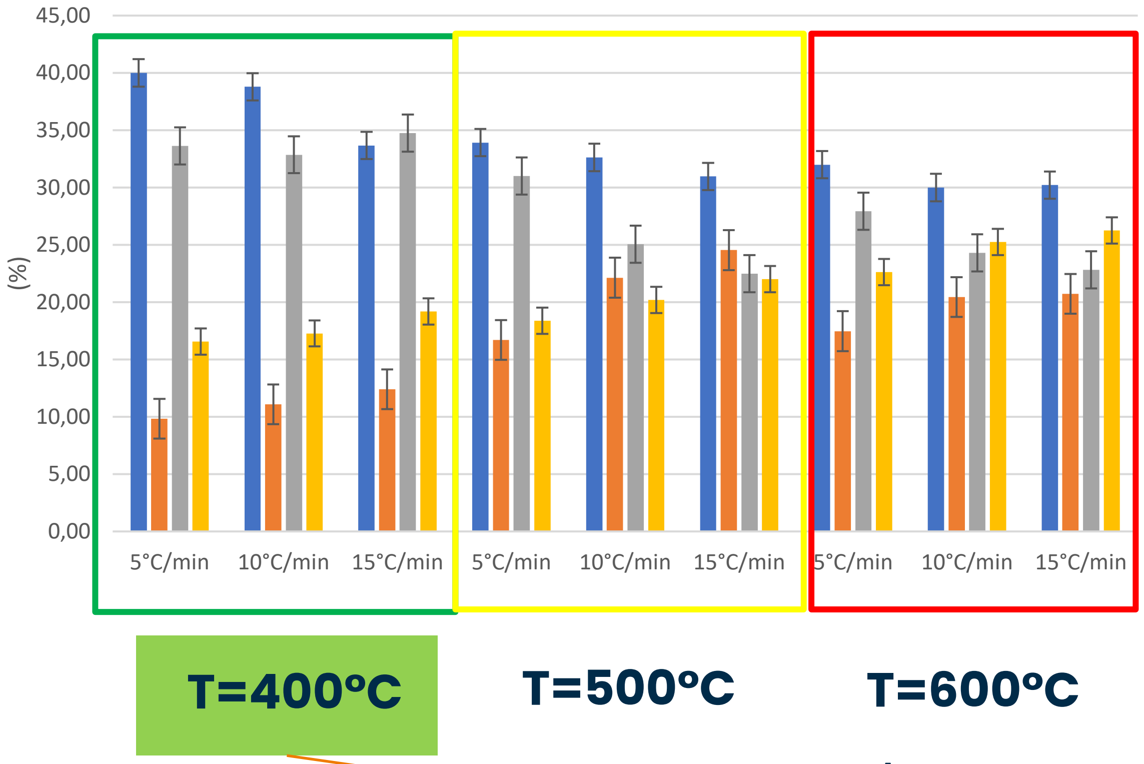
According to (Liu et al., 2020)

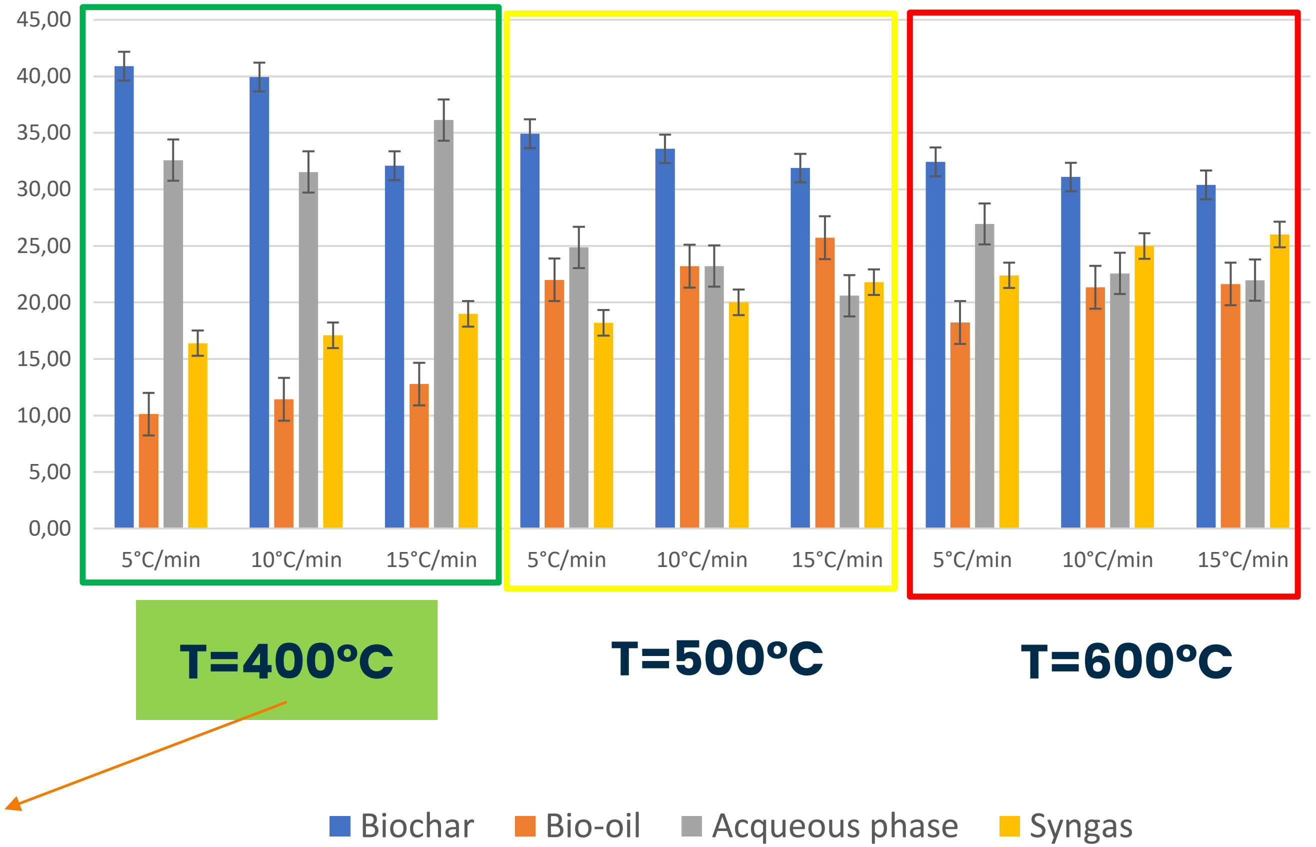
- Total configurations 9
- Tests in duplicate:

Slow pyrolysis: yields

Scenario 1:
Sequential anaerobic digestion and slow pyrolys

Scenario 2:
Sequential hydrodynamic-cavitation+ anaerobic digestion and slow pyrolys



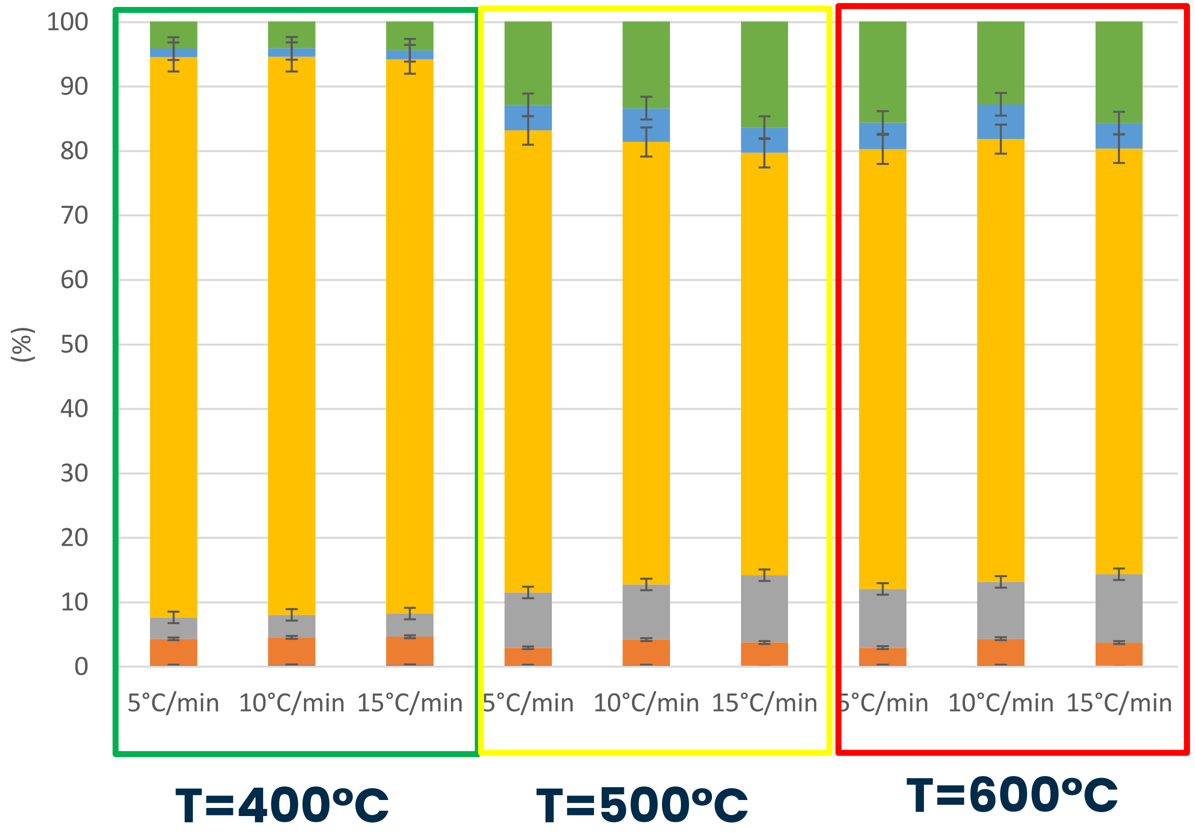


Acqueous fraction of bio-oil >30 %

Slow pyrolysis: syngas composition

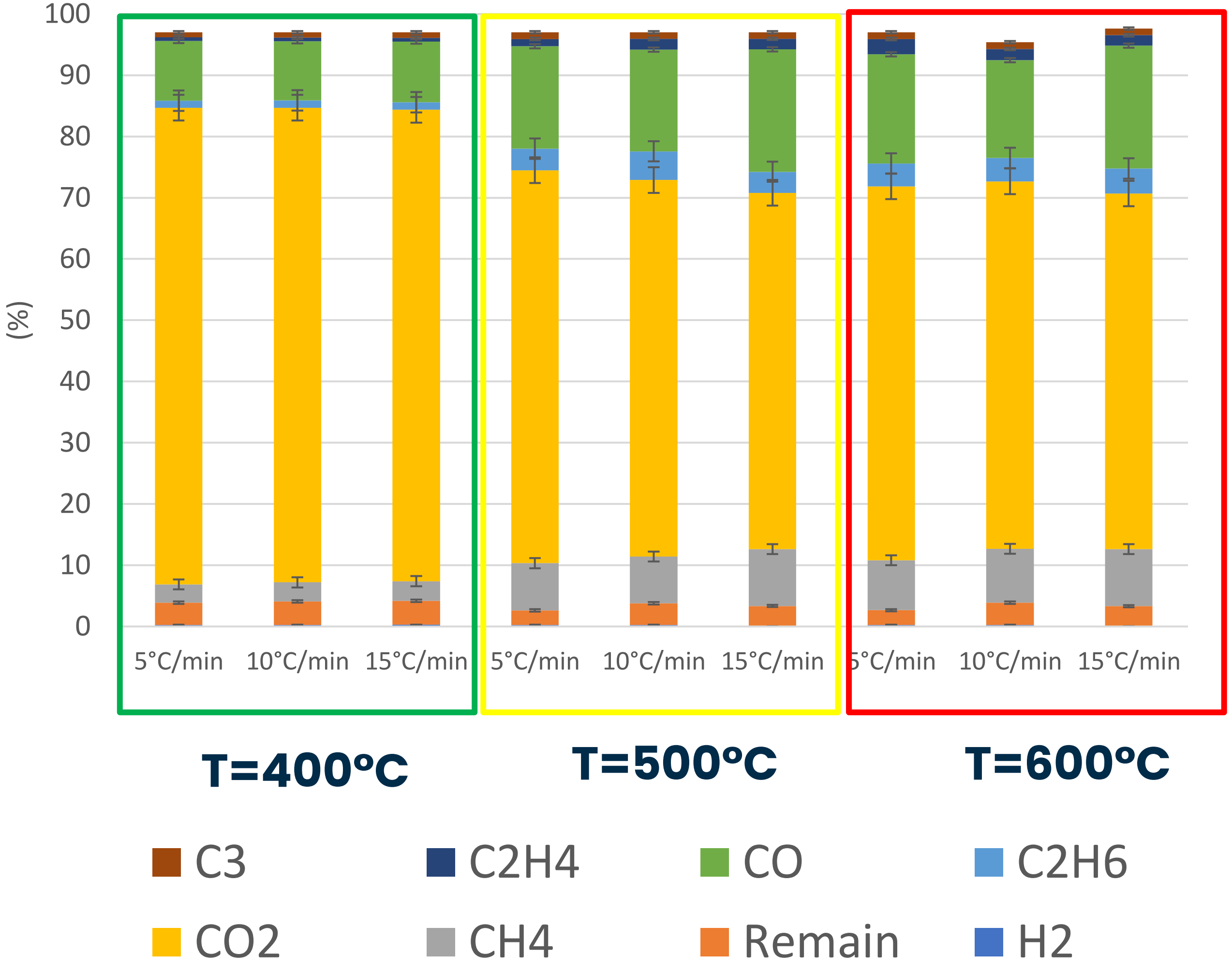
Scenario 1:

Sequential anaerobic digestion and slow pyrolys



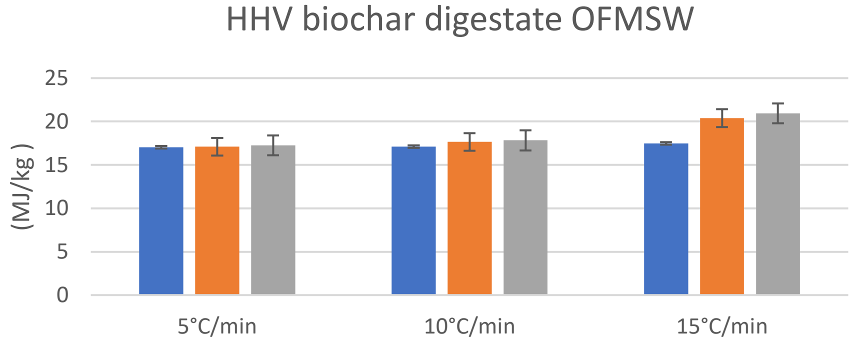
Scenario 2:

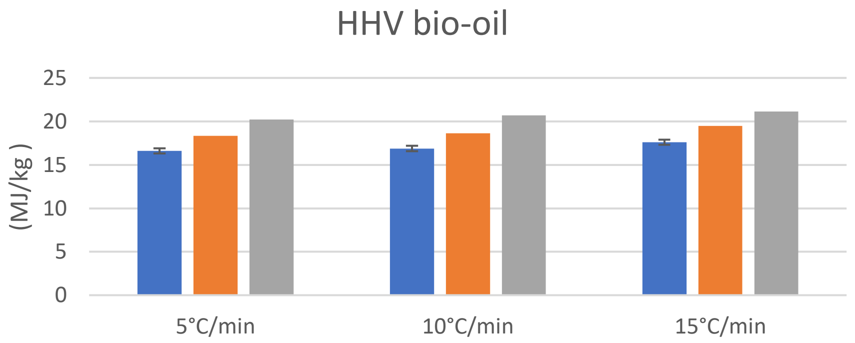
Sequential hydrodynamic-cavitation+ anaerobic digestion and slow pyrolys

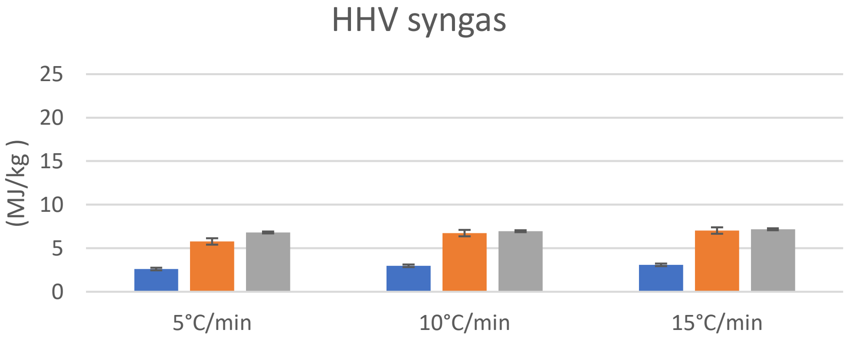


Slow pyrolysis: High heating values

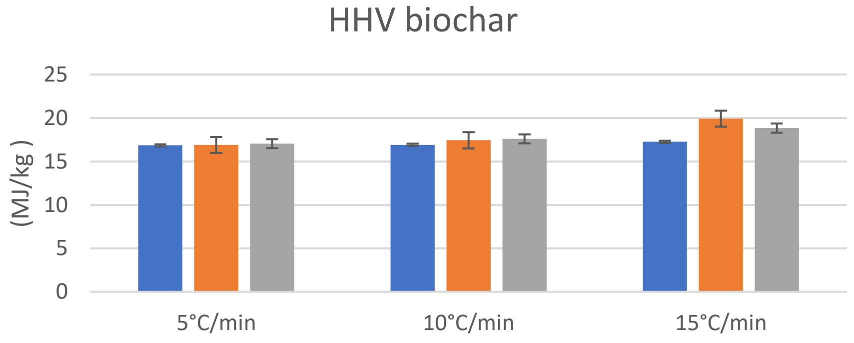
Scenario 1:

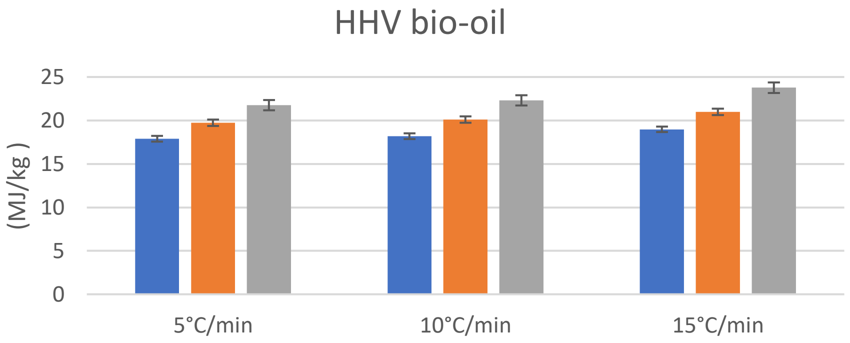


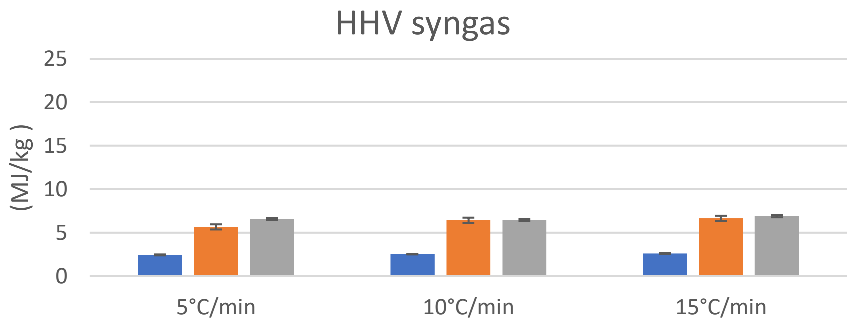




Scenario 2:







HHV biochar

Scenario I > Scenario II
Beacuse HC digestate has higher ash content

HHV bio-oil

Scenario I < Scenario II
Beacuse HC digestate has smaller particle size

HHV bio-oil

Scenario I > Scenario II
Beacuse HC digestate has minor lignocellulosic ammount

Energy and environmental assessment of the integrated and sequential process

Energy assesment:

OFMSW treated: 55 t/d

AD:

Energy produced

- CH_4 produced in AD= 10 kWh/Nm^3
- Electricity conversion= 35 %;
- Heat conversion = 45 %.

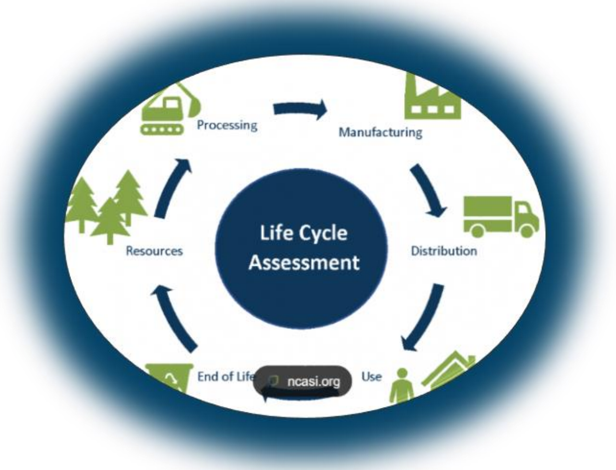
Energy consumed:

- Scenario I = 10 % of energy produced;
- Scenario II = 20 % of energy produced.

Pyrolysis:

Energy to dry and evaporate the wet digestate;
Energy to carry out the pyrolysis;
Energy produced from bio-oil and syngas valorisation.

Environmental assessment

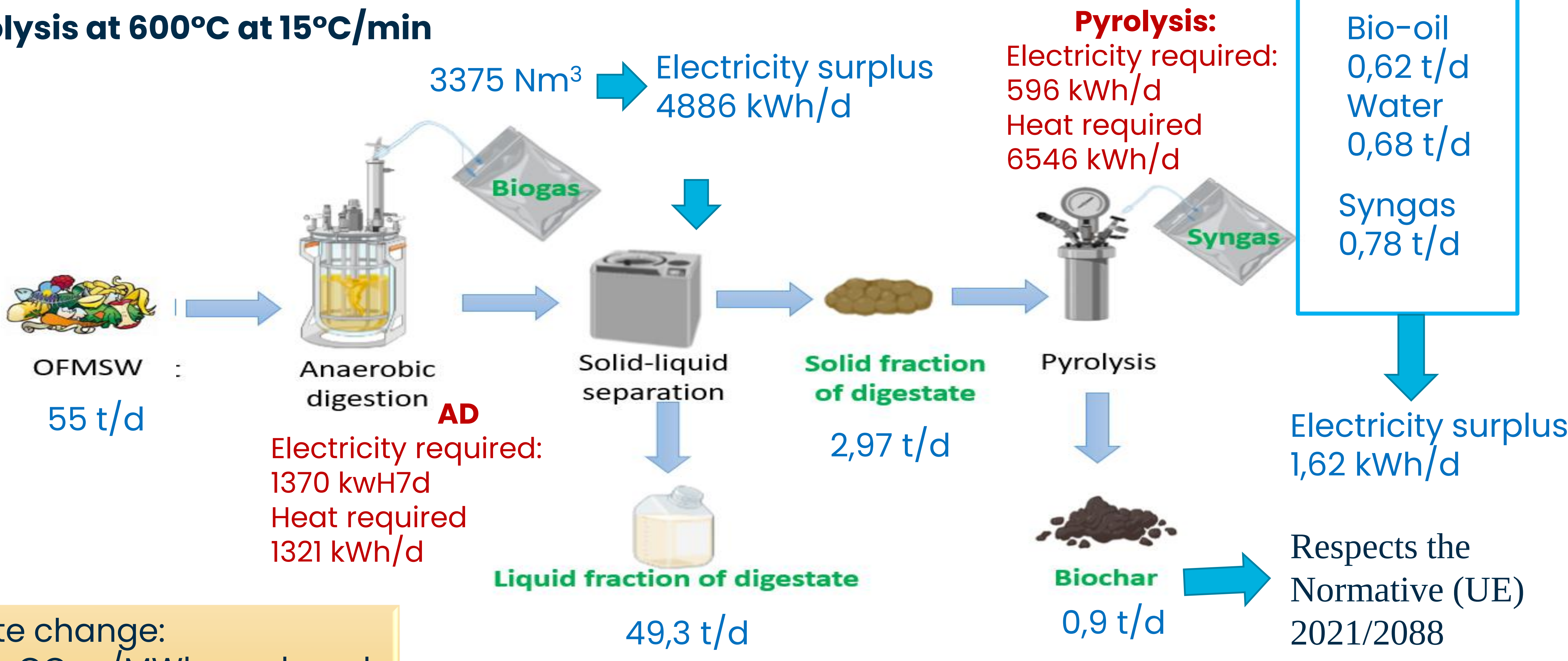


Life Cycle Assessment:
Sima Pro 9.2, database Ecoinvent 3.3

From cradle to grave
FU= 1 MWh of produced energy
Method: Recipe MidPoint (H)
Biocahr carbon capture effect was neglected.

Energy and environmental assesment of the integrated and sequential process

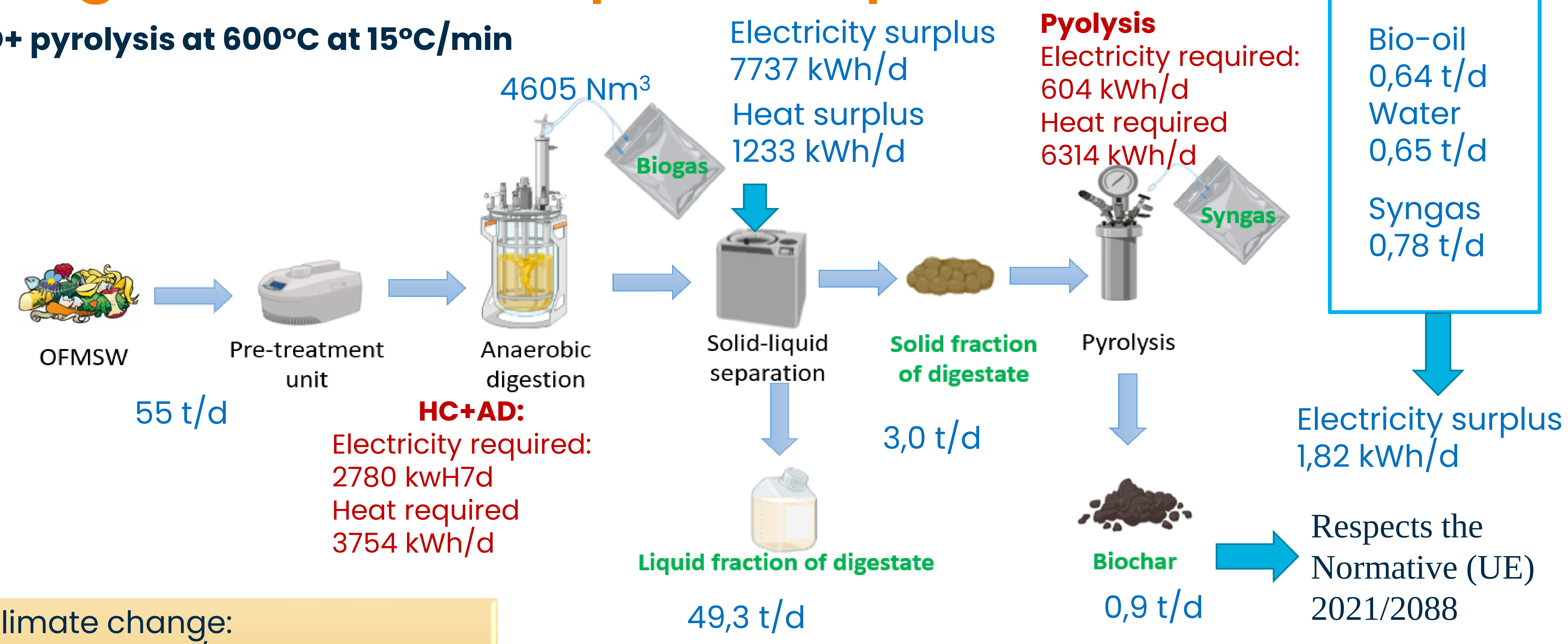
AD+ pyrolysis at 600°C at 15°C/min



Climate change:
-1,70 $kgCO_{2eq}$/MWh produced

Energy and environmental assesment of the integrated and sequential process

AD+ pyrolysis at 600°C at 15°C/min



Climate change:
-3,95 $kgCO_{2\,eq}$/MWh produced

Conclusions and future prospectives

- The integrated and sequential anaerobic digestion and slow pyrolysis has double advantages:
  - production of energy and high added value products;
  - reduction of waste volume.
- The hydrocavitation pretreatment improve both quality of biogas and digestate for biochar production
- Among the pyrolysis tested configurations all configurations satifyied the biochar quality of Normative (UE) 2021/2088, excpet the ones performed at 400 °C.
- Among the tested configurations the integrated anaerobic digestion and slow pyrolysis performed at 600°C at 15 °C achieved the best energy and CO_2 emission reduction.
- The integrated hydrodynamic pretreated anaerobic digestion and slow pyrolysis performed at 600°C at 15 °C achieved the best CO_2 emission avoidment: -3,96 $KgCO_2eq/MWh$
- Future steps: deeper development of Life Cycle Assessment and development of Life Cycle Costing

Thank you for the attention

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