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réseau REUSE

Opportunities and challenges for resource recovery from urban wastewater

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Vniversitat de València | School of Engineering (ETSE-UV) | CalAgua Unidad Mixta UV-UPV | iiama Research Institute of Water and Environmental Engineering | Universitat Politècnica de València

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Presentation of CALAGUA Research Joint Unit

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1. Presentation of CALAGUA Research Joint Unit

Universitat de València · School of Engineering (ETSE-UV) + iiama Research Institute of Water and Environmental Engineering · Universitat Politècnica de València

Interuniversity group made up of more than thirty people, of which 20 are doctors and 4 of them full professors

Main line of research: Application of circular economy principles to the field of urban wastewater treatment.

We develop technologies for the leverage of resources present in wastewater

Organic matter | **Nutrients** | **Reclaimed water**

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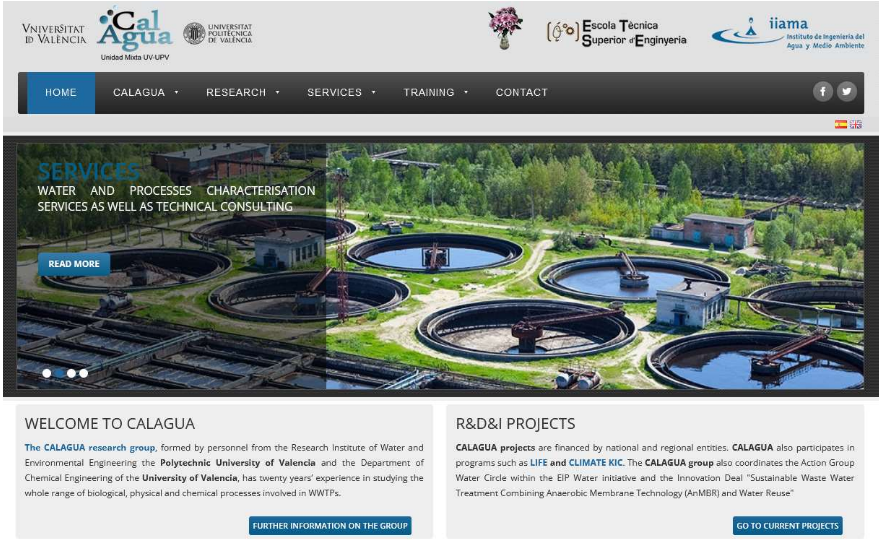
1. Presentation of CALAGUA Research Joint Unit



www.aguas-residuales.es

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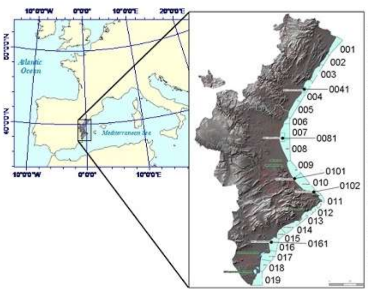
1. Presentation of CALAGUA Research Joint Unit

Main research lines, among others:

- **Priority and emerging pollutants and water quality.**



COASTAL WATERS

CODE	DENOMINATION
001	Comunidad Valenciana boundary – Irta mountain range
002	Irta mountain range
003	Irta mountain range – Cape Oropesa
004	Cape Oropesa - Burriana
005	Burriana - Canet d'en Berenguer
007	North coast of Valencia
008	Port of Valencia - Cape Cullera
009	Cape Cullera - Port of Gandia
010	Port of Gandia – Cape San Antonio
011	Cape San Antonio – Cape Moraira
012	Cape Moraira – Rock of Ifach
013	Rock of Ifach - Cape Les Caletes
014	Cape Les Caletes - Cliff Aguas de Busot
015	Cliff Aguas de Busot - Cape Huertas
016	Cape Huertas - Santa Pola
017	Santa Pola - Guardamar del Segura
018	Guardamar del Segura- Cape Cervera
019	Cape Cervera – Comunidad Valenciana boundary

HEAVILY MODIFIED COASTAL WATERS

CODE	DENOMINATION
0041	Port of Castellón
006	Port of Sagunto
0081	Port of Valencia
0101	Port of Gandia
0102	Port of Denia
0161	Port of Alicante

Monitoring of priority activities on the coast of the Valencian Community.

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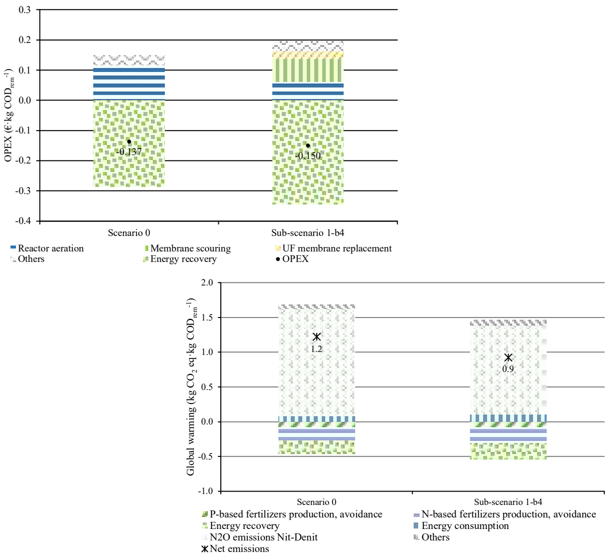
1. Presentation of CALAGUA Research Joint Unit

Main research lines, among others:

- Priority and emerging pollutants and water quality.
- **Economic and environmental sustainability.**

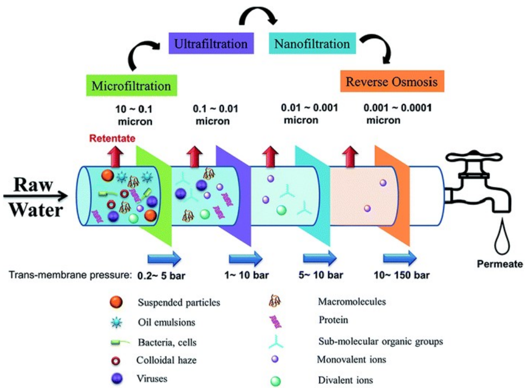


Source: Jiménez-Benítez et al., (2024) Ultrafiltration after primary settler to enhance organic carbon valorization: Energy, economic and environmental assessment. J. Water Process Eng. 58. https://doi.org/10.1016/j.jwpe.2024.104892

1. Presentation of CALAGUA Research Joint Unit

Main research lines, among others:

- Priority and emerging pollutants and water quality.
- Economic and environmental sustainability.
- **Membranes for wastewater treatment.**



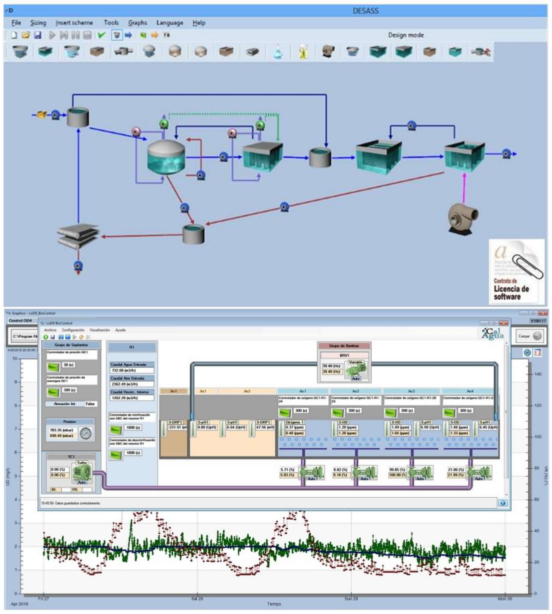
Source: Selatileab et al., (2018) Recent developments in polymeric electrospun nanofibrous membranes for seawater desalination. RSC Advances; 8, 37915-37938. DOI: 10.1039/c8ra07489e

1. Presentation of CALAGUA Research Joint Unit

Unidad Mixta UV-UPV

Main research lines, among others:

- Priority and emerging pollutants and water quality.
- Economic and environmental sustainability.
- Membranes for wastewater treatment.
- **Control and optimisation: specific software development (DESASS and LoDif)**



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Introduction

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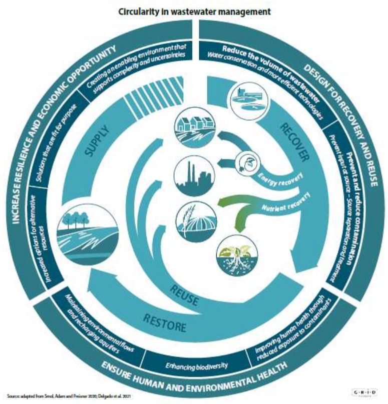
1. Introduction

Application of the Circular Economy principles to water management:

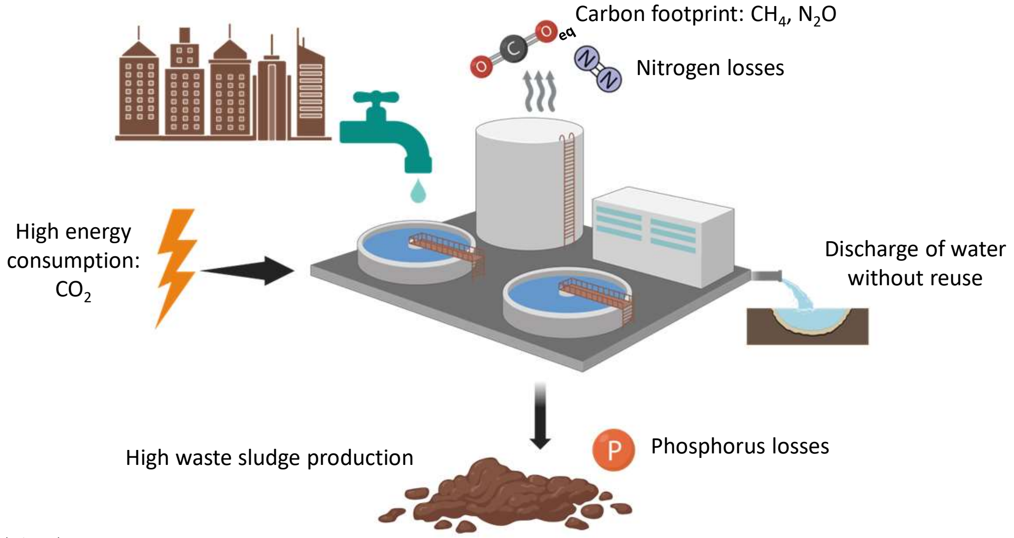
Application of comprehensive production and consumption strategies aimed at maintaining materials and energy within economic activity for as long as possible, thus reducing the consumption of new resources and the diminishing generation of waste and polluting emissions.



Source: United Nations Environment Programme (2023). Wastewater – Turning Problem to Solution. A UNEP Rapid Response Assessment. Nairobi. DOI: https://doi.org/10.59117/20.500.11822/43142

1. Introduction

Conventional water treatments and their sustainability:



Source: Created with BioRender.com

1. Introduction

Innovative water treatments and sustainability:

Source: www.pixabay.com

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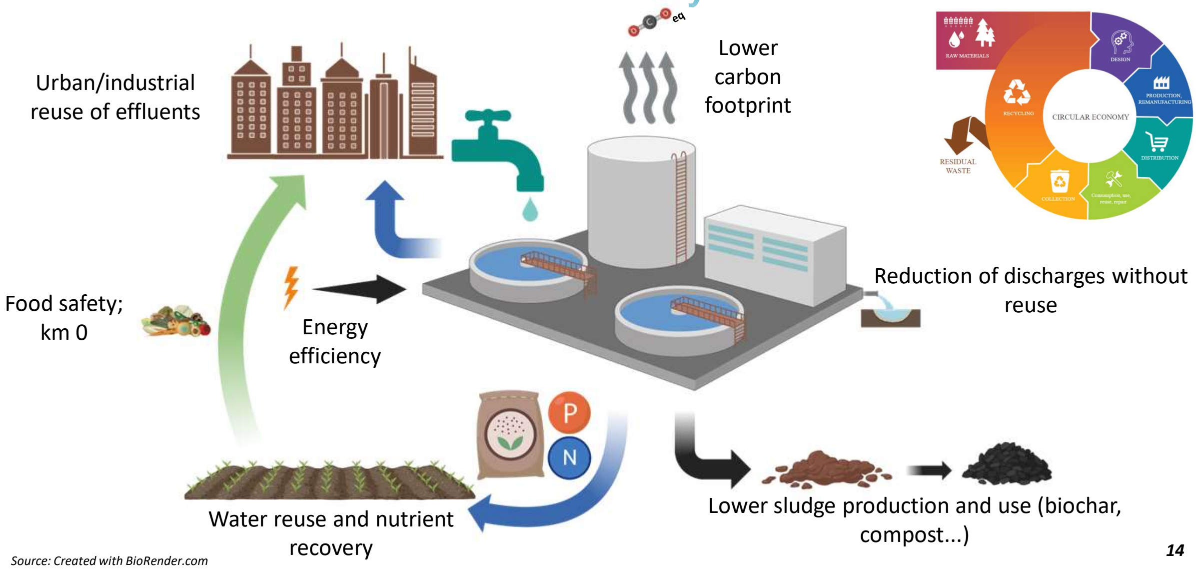
1. Introduction

Innovative water treatments and sustainability:



Source: Created with BioRender.com

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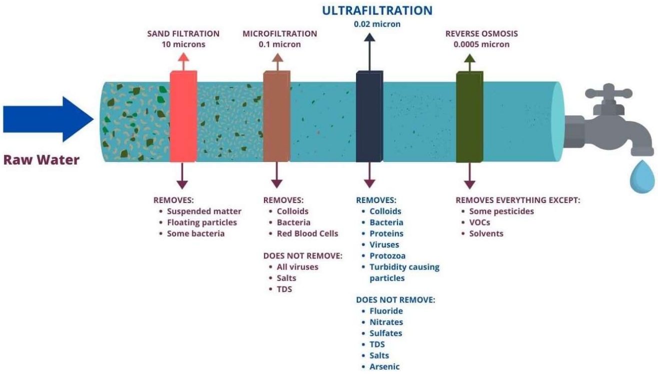
1. Introduction

Application of UF technology in wastewater treatment

- **Advantages:**
  - **Retention of solids and colloids.**
  - **It allows the uncoupling of HRT and CRT in biological treatments.**
  - **Disinfection.**
  - **Turbidity.**



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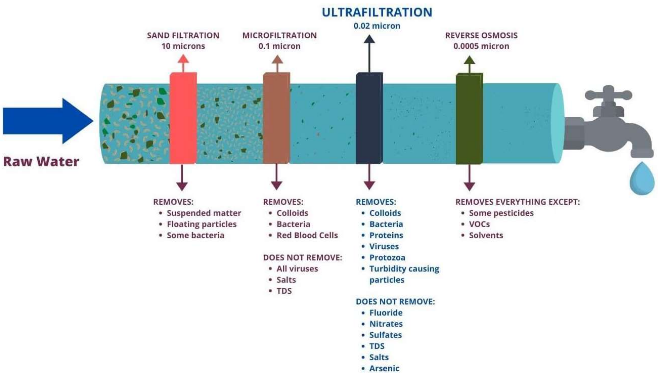
1. Introduction

Application of UF technology in wastewater treatment

- **Challenges:**
  - **Fouling → operation control.**
  - **Cost → expected to decrease as its implementation increases.**



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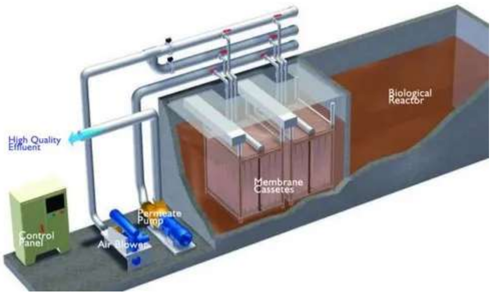
1. Introduction

Combination of UF technology and anaerobic treatment: AnMBR technology

- **Additional advantages:**
  - **Compact systems→ low footprint.**
  - **Potential to valorize 100% of the resources present in the influent: organic matter, nutrients and water.**



Fuente: https://dir.indiamart.com/impcat/membrane-bio-reactors.html

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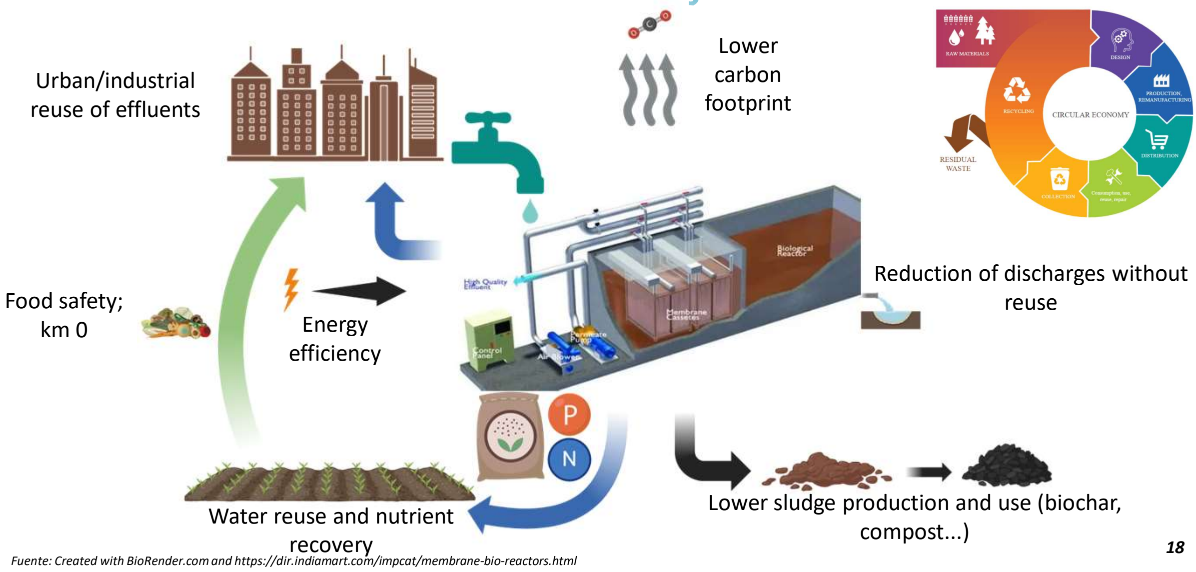
1. Introduction

Innovative water treatments and sustainability:



Fuente: Created with BioRender.com and https://dir.indiamart.com/impcat/membrane-bio-reactors.html

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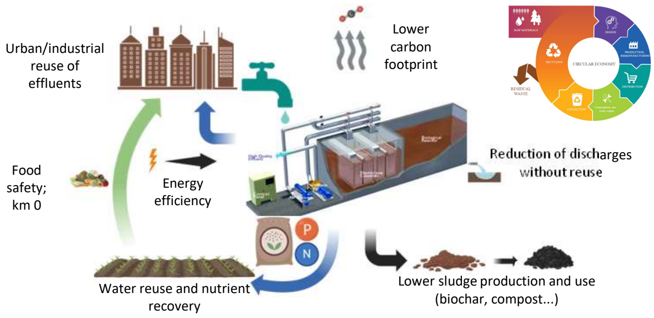
1. Introduction

To be addressed for agriculture reuse, among others:

- **Irrigation seasonality**
- **Health and environmental protection:**
  - **Nutrient content**
  - **Disinfection**



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AnMBR

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3. AnMBR

Journal of Environmental Chemical Engineering 11 (2023) 110267

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Life cycle costing of AnMBR technology for urban wastewater treatment: A case study based on a demo-scale AnMBR system

A. Jiménez-Benítez [a,*], A. Ruiz-Martínez [a], J. Ferrer [b], J. Ribes [a], F. Rogalla [c], A. Robles [a]

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[c] FCC Aqualia, S.A., Avenida Camino de Santiago, 40, 28050 Madrid, Spain

Journal of Environmental Chemical Engineering 11 (2023) 111141

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ELSEVIER

Life cycle assessment of AnMBR technology for urban wastewater treatment: A case study based on a demo-scale AnMBR system

A. Jiménez-Benítez [a,*], J.R. Vázquez [c], A. Seco [a], J. Serralta [b], F. Rogalla [c], A. Robles [a]

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3. AnMBR

INFLUENT	Units	I	II	III	IV	V
Flow rate	L·d⁻¹	21228±591	33016±2773	33243±3118	34207±1478	20984±7482
TSS	mg·L⁻¹	462±188	418±293	332±145	354±116	430±120
COD	mg·L⁻¹	1285±429	1403±532	896±201	755±224	1038±238
N_T	mg N·L⁻¹	52.0±13.3	54.7±16.3	46.8±6.9	46.0±11.2	35.6±8.0
P_T	mg P·L⁻¹	10.1±2.8	8.6±2.1	8.5±1.2	6.8±1.3	7.6±1.1
SO_4^{2-}-S	mg S·L⁻¹	147.7±13.3	172.2±28.5	125.4±47.6	157.3±46.9	149.7±26.9
EFFLUENT	**Units**	**I**	**II**	**III**	**IV**	**V**
COD	mg·L⁻¹	91±31	116±24	121±15	80±17	79±18
N_T	mg N·L⁻¹	47.9±6.2	54.0±14.6	47.3±4.3	52.5±10.2	37.0±11.1
P_T	mg P·L⁻¹	8.8±1.9	9.9±1.9	6.9±2.8	6.3±0.5	7.8±1.2
CH_4	mg·L⁻¹	16.0±0.5	17.1±0.8	17.9±0.3	16.3±0.5	18.7±0.6
REACTOR	**Units**	**I**	**II**	**III**	**IV**	**V**
SRT	d	70±1	68±2	70±2	71±2	70±0
HRT	h	41±1	25±1	26±2	26±2	41±13
T	ºC	27±1	24±2	19±1	27±1	18±2
MLTSS	g·L⁻¹	8.4±0.5	12.6±0.5	11.3±1.0	10.4±0.8	8.3±1.2
N_T	mg N·L⁻¹	505.8±139.4	579.0±68.7	509.0±133.6	339.9±63.5	269.5±94.4
P_T	mg P·L⁻¹	96.8±12.3	106.6±10.7	89.4±14.9	93.2±6.2	83.7±6.9
Waste sludge	L·d⁻¹	522±5	511±107	521±5	510±18	520±4
Biogas prod.	L STP·d⁻¹	5396±4435	5558±3204	1901±597	1359±999	2241±924
%CH₄	%	77±2	77±2	72±2	77±2	76±1
MEMBRANES	**Units**	**I**	**II**	**III**	**IV**	**V**
SGD_P	$Nm^3_{biogas} \cdot m^{-3}_{permeate}$	14	13	12	9	6
$J_{20\ gross}$	LMH	21	19	17	15	18
$J_{20\ net}$	LMH	18	16	15	13	15
TMP	mbar	318	362	462	87	360
FR	mbar·day⁻¹	4.2	4.7	0.3	0.5	4.9
Cleaning frequency	year⁻¹	2.8	3.1	0.2	0.3	3.2

- **SRT: ≈70 días**
- **HRT: 25-41 h**
- **Temperature: 18-27 ºC**

- **COD: 755-1403 mg·L⁻¹**

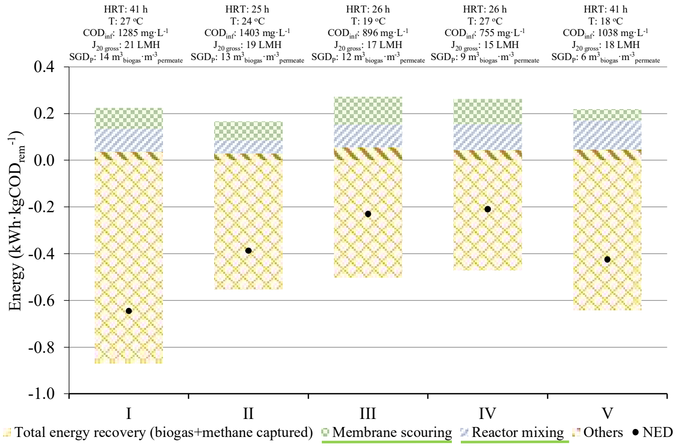
- **Sulfate: 125.4-172.2 $SO_4^{2-}-S$**

- **SGD_P: 6-14 $Nm^3 \cdot m^{-3}$**
- **$J_{20,g}$: 15-21 LMH**

3. AnMBR

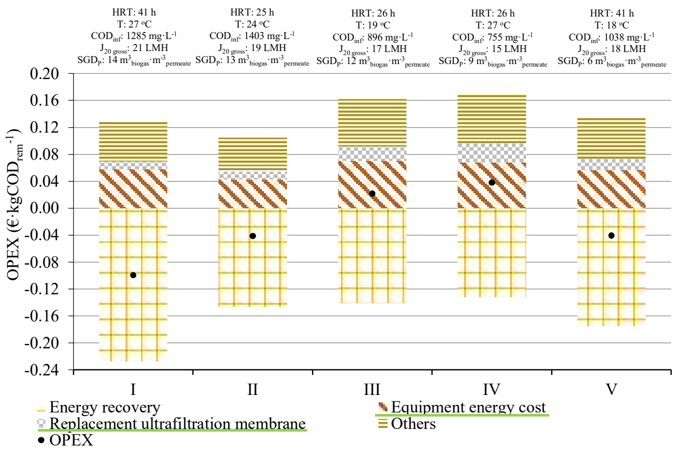
- **Energy recoveries → net productions in all periods between 0.210 (PIII) and 0.645 kWh·kgCOD$_{rem}^{-1}$ (PI).**
- **Higher direct consumption::**
  - **Reactor mixing (34-57 %).**
  - **Membrane scouring (22-48 %).**
- **Optimization:**
  - **↑ COD removals (OLR, T)**
  - **↓ HRT**
  - **↑ Filtration productivity**

Vaccari et al. (2018): net energy demands for CAS of 0.85 kWh·kgCOD$_{rem}^{-1}$.

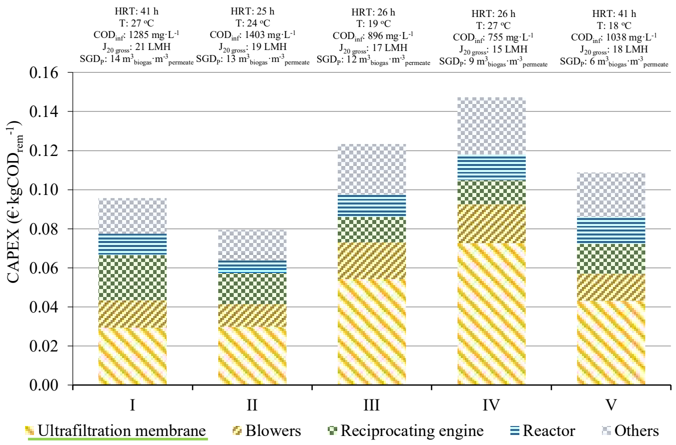


3. AnMBR

- **OPEX: -0.099 €·kgCOD$_{rem}^{-1}$ (PI) y 0.041 €·kgCOD$_{rem}^{-1}$ (PIV).**
- **Energy recovery allows generating savings in PI, PII and PIII.**
- **The main net contributors are::**
  - **Energy cost (41-46 %).**
  - **Membrane replacement (9-17 %).**



3. AnMBR



- **CAPEX: 0.080 €·kgCOD$_{rem}^{-1}$ (PII) y 0.147 €·kgCOD$_{rem}^{-1}$.**
- **The main contributors are:**
  - **UF membranes: 31-49 %**
  - **Blowers: 13-15 %**
  - **CHP: 8-24 %**
  - **Reactor: 8-13 %**

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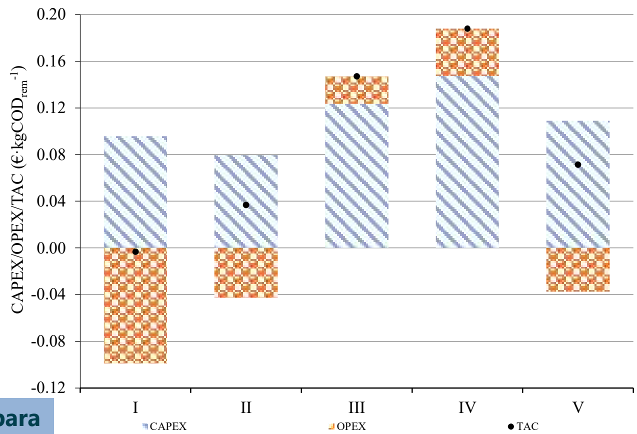
3. AnMBR

- **TAC: -0,003 €·kgDQO$_{rem}^{-1}$ (PI) y 0.188 €·kgDQO$_{rem}^{-1}$ (PIV).**
- **The lower cost of PI is due to**
  - **>Lower membrane requirements → High $J_{20,g}$ (21 LMH)↓**
  - **Energy recovery→ OPEX.**
- **CAPEX and OPEX show significant contribution → TAC optimization**

Bertanza et al. (2017): 1.18-2.51 €·kgDQO$_{rem}^{-1}$ para CAS.
Jafarinejad (2017): 0.93-0.95 €·kgDQO$_{rem}^{-1}$ para CAS (simulación).



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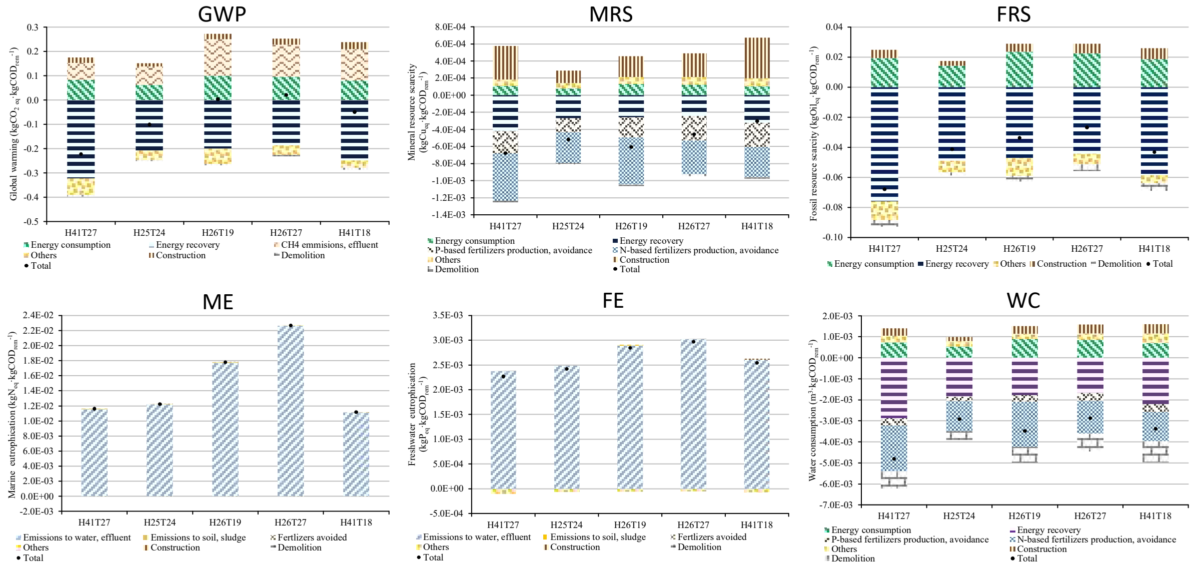
3. AnMBR



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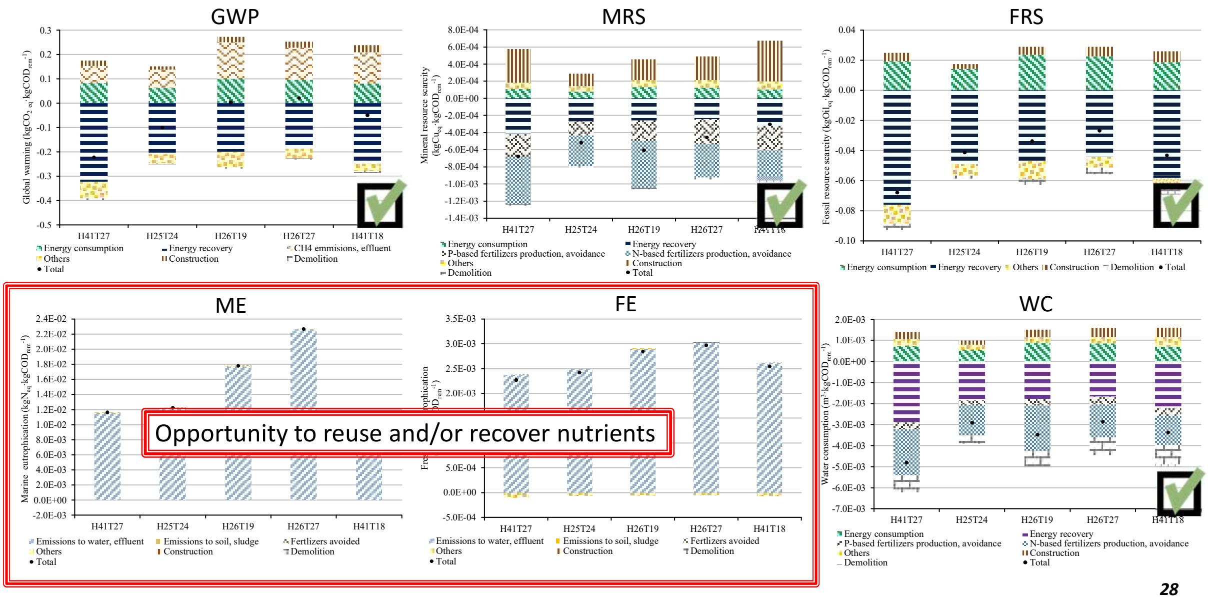
3. AnMBR



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Fertigation

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4. Fertigation

Journal of Cleaner Production 270 (2020) 122398

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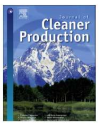

AnMBR, reclaimed water and fertigation: Two case studies in Italy and Spain to assess economic and technological feasibility and CO_2 emissions within the EU Innovation Deal initiative

Antonio Jiménez-Benítez [a], Francisco Javier Ferrer [c], Silvia Greses [a, 1], Ana Ruiz-Martínez [a], Francesco Fatone [d], Anna Laura Eusebi [d], Nieves Mondéjar [c], José Ferrer [b], Aurora Seco [a, *]

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[c] Júcar River Basin Authority, Av. Blasco Ibáñez 48, 46010, Valencia, Spain
[d] Department of Science and Engineering of Materials, Environment and Urban Planning, Università Politecnica Delle Marche, Ancona, Italy

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4. Fertigation

Innovation Deal

INNOVATION DEAL on Sustainable Wastewater Treatment Combining Anaerobic Membrane Technology and Water Reuse

Objective: quantify the benefits of water reuse through case studies.

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4. Fertigation

Case study: Oliva (Comunitat Valenciana)

- **Non-sensitive according to Directive 91/271/CEE.**
- **Vulnerable zone according to Directive 91/676/CEE.**
- **Coastal discharge.**
- **Irrigation demand: 3.4 hm^3·year^{-1} supplied by aquifer pumping (Scenario I, SI).**
- **Agricultural area: 582 ha**
- **Crop: citrus.**
- **Irrigation system analysis: traditional vs localized irrigation.**

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4. Fertigation

Case study: Oliva (Comunitat Valenciana)

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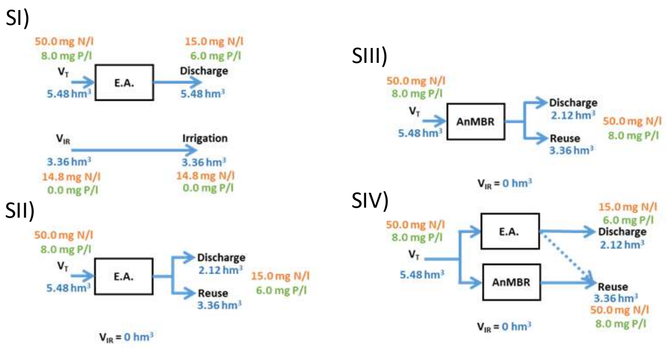

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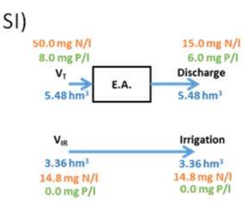
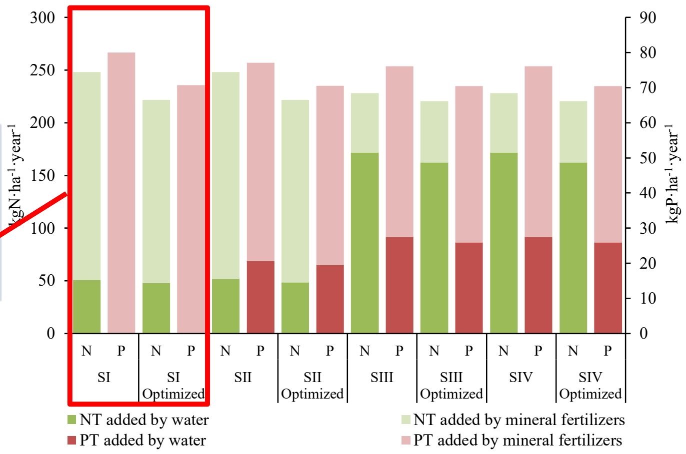
4. Fertigation

Case study: Oliva (Comunitat Valenciana)

1 → 2 → 3

Scenario I (SI) covers only 22-23% of the N needs and does not provide P.





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4. Fertigation

Case study: Oliva (Comunitat Valenciana)

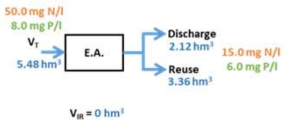
1 → 2 → 3

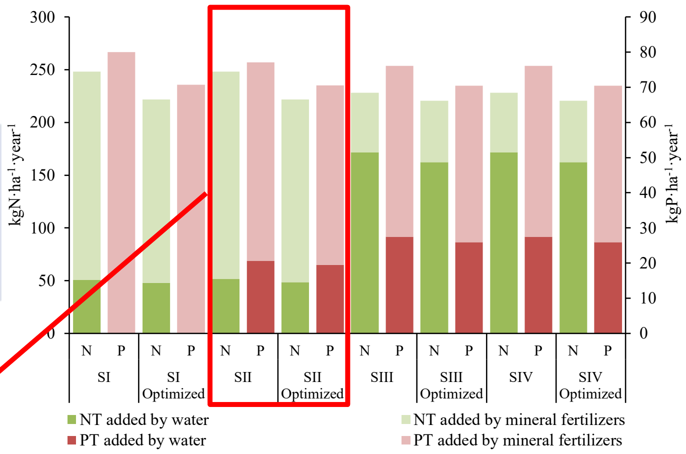
Scenario I (SI) covers only 22-23% of the N needs and does not provide P.

Scenario II (SII) allows P to be incorporated until 27-30% of the needs are covered.

The scenarios with AnMBR (SIII and SIV) allow 74-78% of N and 37-39% of P to be covered.

SII)





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4. Fertigation

Case study: Oliva (Comunitat Valenciana)

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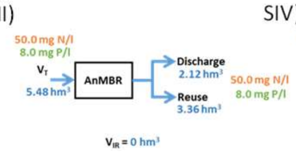
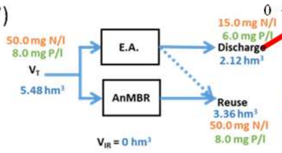
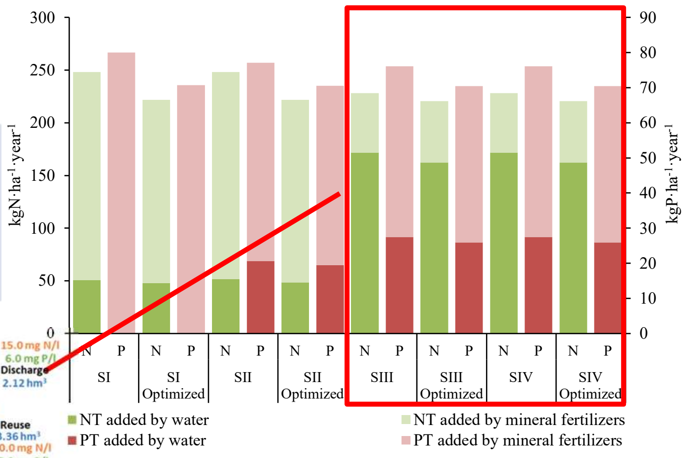
SIII)



SIV)





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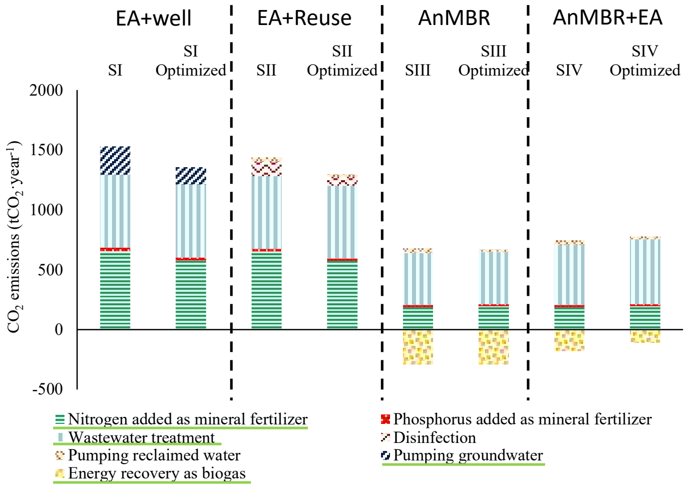
4. Fertigation

Case study: Oliva (Comunitat Valenciana)

- **Reduction of CO_2 emissions in the AnMBR scenarios (SIII and SIV) occurs mainly due to:**
  - **No well pumping.**
  - **Reduction of treatment emissions.**
  - **Lower needs for industrial fertilizers.**
  - **Energy valorization of organic matter.**



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4. Fertigation

Case study: Oliva (Comunitat Valenciana)

		EA+well		EA+Reuso		AnMBR		AnMBR+EA	
Costs	**Units**	**SI**	**SI opt**	**SII**	**SIIopt**	**SIII**	**SIIIopt**	**SIV**	**SIVopt**
Wastewater treatment C_{WWT}	k€·year⁻¹	257.0	257.0	257.0	257.0	93.9	93.9	156.8	195.7
Discharge fee $C_{Discharged\ fee}$	k€·year⁻¹	21.9	21.9	8.5	13.7	8.5	13.7	8.5	13.7
WWTP cost	k€·year⁻¹	*278.9*	*278.9*	*265.5*	*270.7*	*102.4*	*107.6*	*165.3*	*209.4*
Extra treatment for reuse $C_{rteat\_for\_reuse}$ (4)	k€·year⁻¹	0.0	0.0	15.0	9.0	0.0	0.0	0.0	0.0
Pumping for reuse $C_{Pumping\text{-}WWT}$ (3)	k€·year⁻¹	0.0	0.0	16.0	9.7	16.0	9.7	16.0	9.7
WWTP + RWTP cost	k€·year⁻¹	*278.9*	*278.9*	*296.5*	*289.4*	*118.4*	*117.3*	*181.3*	*219.1*
Fertilisers $C_{Fertilizers}$	k€·year⁻¹	92.0	81.1	87.0	77.2	31.0	31.1	31.0	31.1
Pumping groundwater $C_{Pumping}$	k€·year⁻¹	110.0	67.3	0.0	0.0	0.0	0.0	0.0	0.0
Farming cost	k€·year⁻¹	*202.0*	*148.4*	*87.0*	*77.2*	*31.0*	*31.1*	*31.0*	*31.1*
Total C_{Total}	k€·year⁻¹	480.9	427.3	383.5	366.6	149.4	148.4	212.3	250.2
Flow WWTP to manager (2)	k€·year⁻¹	0	0.0	13.4	8.2	176.6	171.3	113.7	69.5
Flow farmer to manager (5)	k€·year⁻¹	0	0.0	115.0	71.2	171.0	117.4	171.0	117.4
RWM Balance	k€·year⁻¹	0	0.0	97.4	60.5	331.6	279.0	268.7	177.1

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5

Nutrients recovery

5. Nutrients recovery

Integration of technologies into a new EDAR

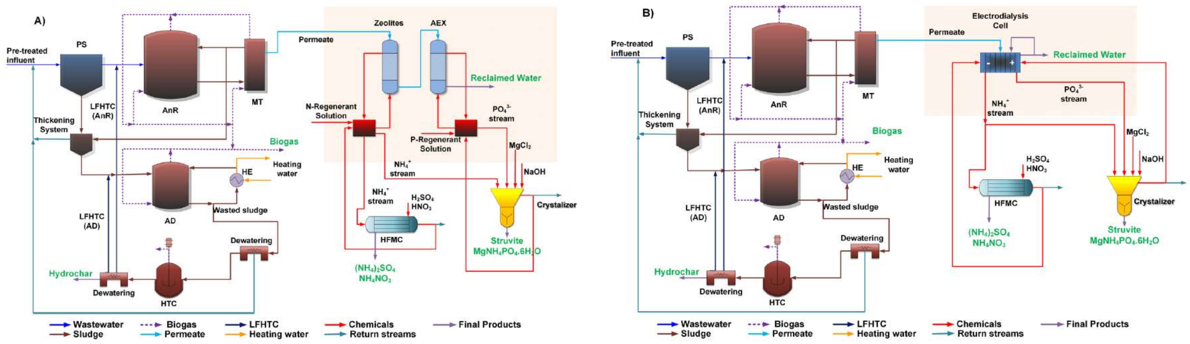
- Nutrient recovery technologies require higher concentrations of N and P than the AnMBR permeate.
- A post-treatment of the AnMBR permeate is needed when it cannot be reused for irrigation. It should be a physical-chemical treatment (on-off immediately) with a double purpose:
  - Produce an effluent free of nitrogen and phosphorus suitable for discharge.
  - Obtain a suitable nitrogen and phosphorus concentration for recovery.

- Alternatives
  - Electrodialysis
  - Ion exchange: zeolites and exchange resins

5. Nutrients recovery-RECREATE Project

Transformation of wastewater treatment plants into Resource rEcovery facilities by applying the principles of the CiRcular Economy and sAniTary and Environmental security - RECREATE coordinated R&D&i project (PID2020-114315RB-C21 and PID2020-114315RB-C22) funded by the Ministry of Science and Innovation and the National Research Agency (MCIN/AEI/10.13039/501100011033).

RECREATE



RECREATE treatment schemes proposed: A) nutrient concentration with ion exchange processes; B) nutrient concentration with electrodialysis process.

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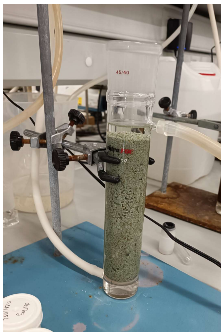
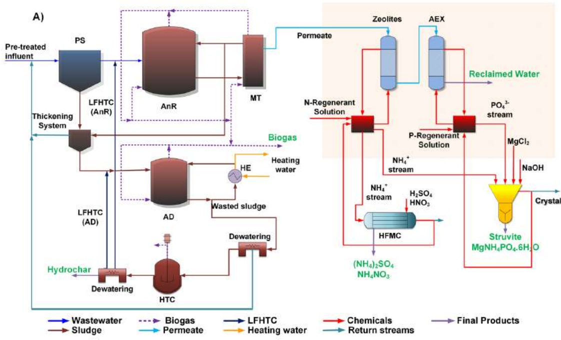
5. Nutrients recovery-Ion Exchange

WWTP Carraixet (Valencia, Spain)

└──→ *AnMBR plant*



To study the feasibility of ammonium and phosphate concentration by applying an Ion Exchange process to the effluent of an AnMBR for subsequent recovery



RECREATE

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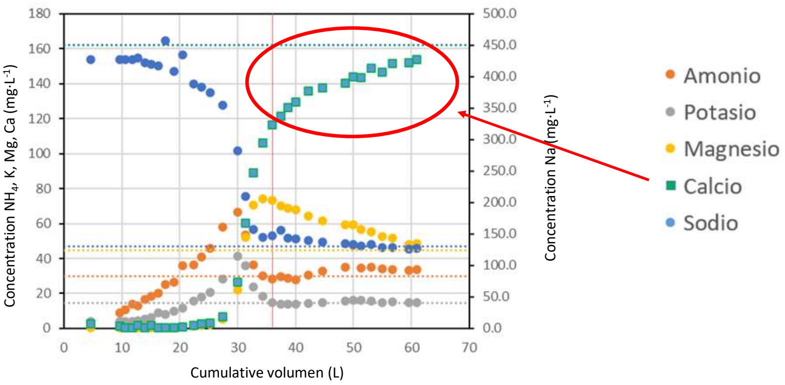
5. Nutrients recovery-Ion exchange

RECREATE

Cationic resin to retain ammonium

- PUROLITE SHALLOW SHELL SSTC60 Resin: Exchanges cations for sodium ions
- It is not useful due to its greater affinity for divalent cations **calcium**, magnesium



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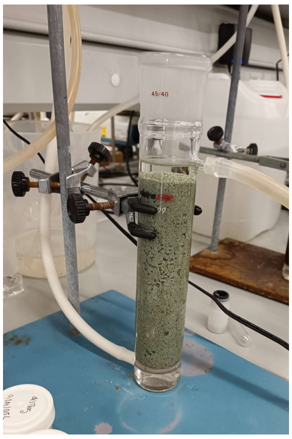
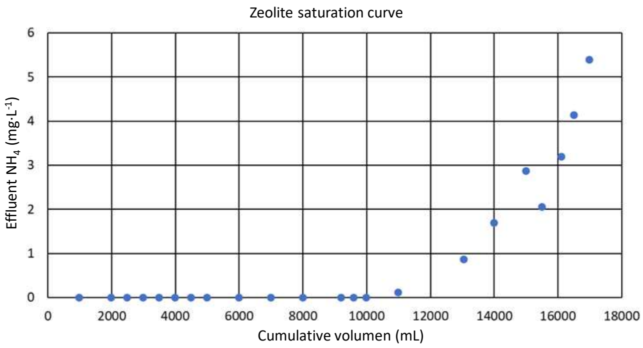
5. Nutrients recovery-Ion exchange

RECREATE

Natural zeolites to retain ammonium

- Zeolite Clinoptilolite: Exchanges cations for sodium ions





Able to treat 120 BV with NH_4^+ < 1 mg N·L^{-1}

Reduced volume → HRT = 3 minutes

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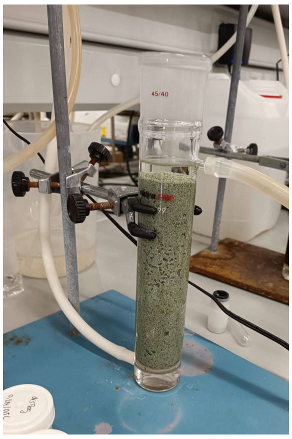
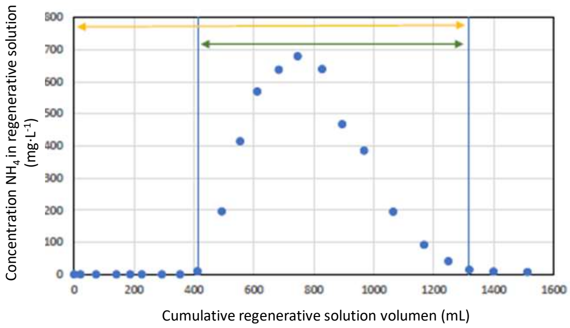
5. Nutrients recovery-Ion exchange

Natural zeolites to retain ammonium

RECREATE

- Zeolite Clinoptilolite: Exchanges cations for sodium ions





Regenerated with NaOH

Regenerative solution obtained: NH_4^+ = 300 mg $N \cdot L^{-1}$ pH = 12

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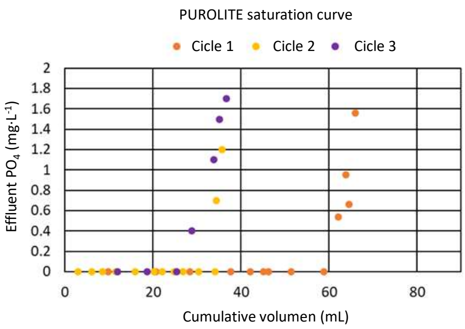
5. Nutrients recovery-Ion exchange

Anion resin to retain phosphate

- PUROLITE FERRIX A33E Resin: Retains phosphate ions by forming complexes with iron oxides. Exchanges phosphate for OH^-



Adsorption yield: 1.75 mg $P \cdot g^{-1}$ resin

Reduced volume → HRT < 2 minutes

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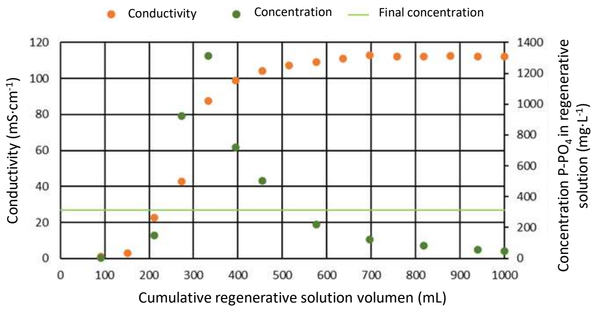
5. Nutrients recovery-Ion exchange

RECREATE

Anion resin to retain phosphate

- PUROLITE FERRIX A33E Resin: Retains phosphate ions by forming complexes with iron oxides. Exchanges phosphate for OH^-



Regenerated with a mixture of NaCl and NaOH

Obtained regenerative solution: PO_4^+ = 310 mg $P \cdot L^{-1}$ pH > 13

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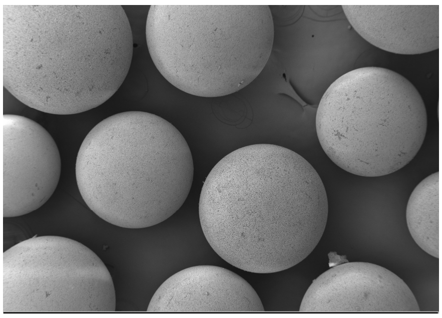
5. Nutrients recovery-Ion exchange

RECREATE

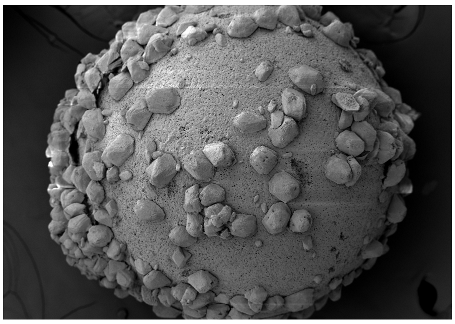
Anion resin to retain phosphate

- PUROLITE FERRIX A33E Resin: Scanning Electron Microscopy

New resin



Saturated resin



These results are part of Laura Ruiz PhD thesis

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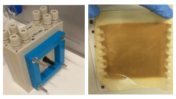
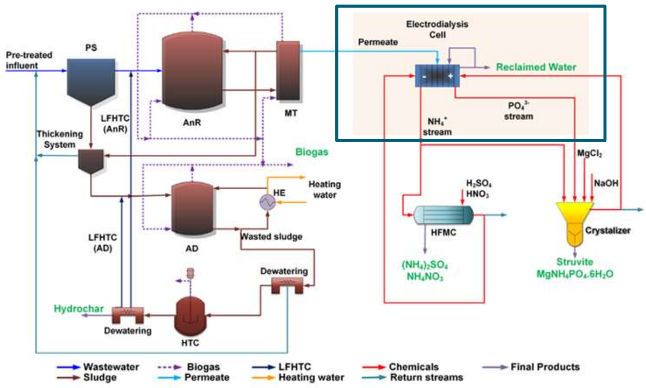
5. Nutrients recovery-Electrodialysis

WWTP Carraixet (Valencia, Spain)

AnMBR plant



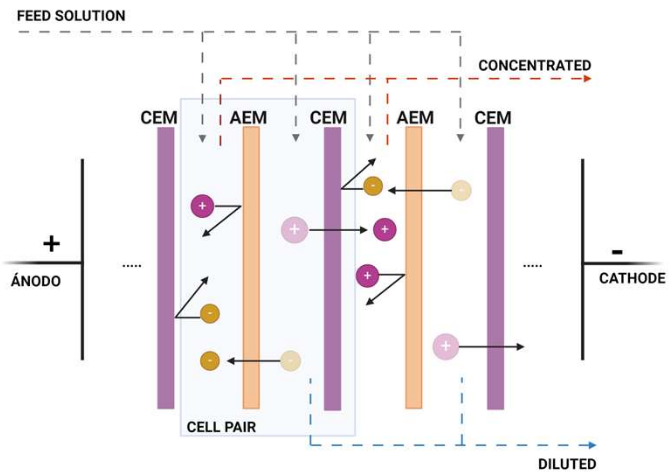
To study the feasibility of ammonium and phosphate concentration by applying an electrodialysis process to the effluent of an AnMBR for subsequent recovery



RECREATE

5. Nutrients recovery-Electrodialysis

Electromembrane process where ions migrate from the anode to the cathode trough alternated cationic and anionic exchange membranes where the electromotive force is the applied voltage.



- To obtain high NH_4-N and PO_4-P **concentrated streams** to apply subsequent nutrient recovery
- To reach discharge limits in **diluted stream** (Directive 91/271/CEE)

RECREATE

5. Nutrients recovery-Electrodialysis

Feed water and operating parameters:

pH	6.82	±	0.1
Conductivity (mS/cm)	1.81	±	0.4
NH_4-N (mg/L)	51.6	±	2.4
PO_4-P (mg/L)	7.90	±	2.0
SO_4-S (mg/L)	**103.11**	±	25.6
Cl (mg/L)	204.1	±	36.6
Na (mg/L)	101.6	±	29.4
K (mg/L)	10.4	±	5.9
Mg (mg/L)	42.0	±	11.9
Ca (mg/L)	**164.0**	±	40.4

AnMBR pilot plant situated at the Carraixet WWTP (Valencia, Spain)

RECREATE

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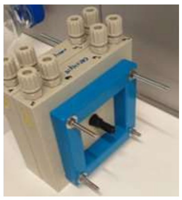
5. Nutrients recovery-Electrodialysis

Feed water and operating parameters:

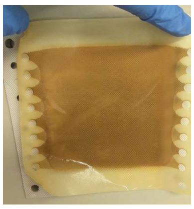
Cell-pairs	10
Stack area	64 cm^2
Flowrate (L/h)	40-45
Current (A)	0.24
Voltage (V)	7.5
Anionic membrane	PC Acid 100 OT
Cationic membrane	PC-SK

Current (A) → Galvanostatic mode

Voltage (V) → Potentiostatic mode



Membrane Type	PC SK	PC Acid 100
General use	Standard desalination	Sulphuric acid
Composition	Sulfonic acid	Ammonium
Resistance (Ω cm^2)	~ 2.5	~ 5
pH stability	0-11	0-10
Thickness (μm)	100-120	80
Max.Temperature (°C)	50	60



RECREATE

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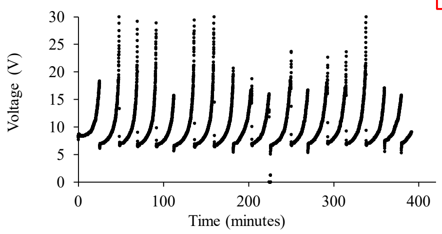
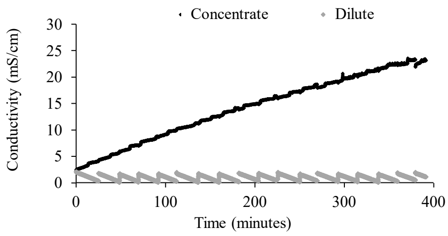
5. Nutrients recovery-Electrodialysis

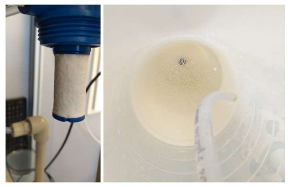
Long-term experiment:

❖ **Precipitation and discharge limits problems**





Concentrations (mg/L)							
Parameter	Feed			Dilute			Concentrate
NH_4-N	57.11	±	6.04	**11.67**	±	2.85	**740.37**
PO_4-P	6.60	±	0.34	**2.57**	±	0.30	**50.05**
SO_4-S	98.49	±	13.45	21.39	±	22.00	1839.01
Mg	39.81	±	0.37	10.36	±	1.83	515.62
Ca	156.81	±	1.10	29.70	±	6.22	2135.66



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5. Nutrients recovery-Electrodialysis

Problems

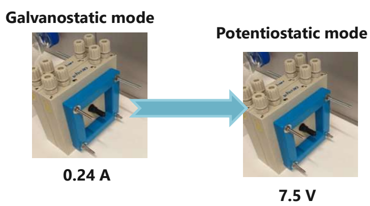
Ca-based precipitation

Discharge limits

Solutions

Cation Exchange Resins

Divalent cationic product separated stream



RECREATE

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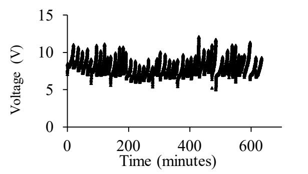
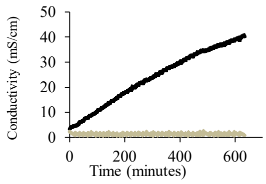
5. Nutrients recovery-Electrodialysis

Ion Exchange Resins pretreatment + two stack in series experiment

Galvanostatic operation at 0.24 A:

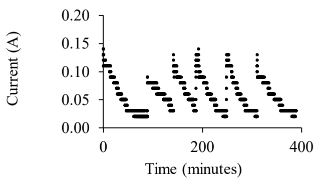
Parameter	Concentrations (mg/L) Feed	Dilute	Concentrate
NH_4-N	52.10 ± 2.29	**18.87** ± 4.88	**1232.61**
PO_4-P	9.98 ± 0.30	**5.00** ± 0.99	***135.49***
SO_4-S	93.00 ± 1.46	**43.65** ± 30.65	***2650.39***
Mg	21.58 ± 1.47	**9.76** ± 2.79	***374.48***
Ca	23.03 ± 1.70	**9.98** ± 4.35	***459.34***

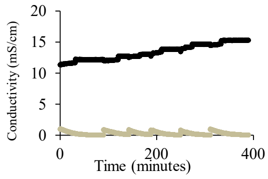




Potentiostatic operation at 7.5 V:

Parameter	Concentrations (mg/L) Feed	Dilute	Concentrate
NH_4-N	**18.87** ± 4.88	**1.50** ± 1.09	**1301.68**
PO_4-P	**5.00** ± 0.99	**1.79** ± 0.09	**189.24**
SO_4-S	**43.65** ± 30.65	**2.37** ± 0.26	**3082.54**
Mg	**9.76** ± 2.79	**0.66** ± 1.75	**535.79**
Ca	**9.98** ± 4.35	**0.33** ± 1.55	**572.00**





RECREATE

These results are part of Patricia Rodríguez PhD thesis

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5. Nutrients recovery-Electrodialysis

- **Decreasing calcium values with cation exchange resins allows reaching target values of ammonium and phosphate in concentrated stream.**
- **Discharge limits in the diluted stream *nearly can be achieved with* two serial ED stack.**
- **Combining both processes (pretreatment with ion exchange resins + serial ED Cell configuration) results in promising values in diluted and concentrated streams.**

RECREATE

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5. Nutrients recovery

Conclusions

- Both technologies (resins and electrodialysis) fulfill the double objective.
  - Retain ammonium and phosphate for discharge to sensitive area.
  - Concentrate nutrients for recovery
- It is necessary to evaluate its long-term operation and an economic study for the optimization of technologies.

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HTC

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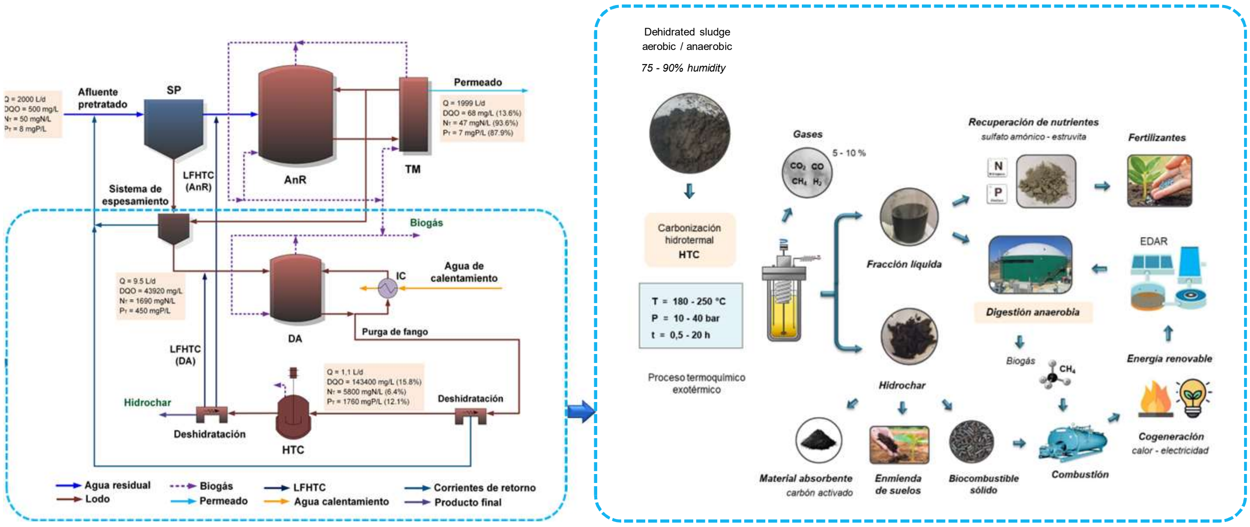
6. HTC

Transformation of wastewater treatment plants into Resource rEcovery facilities by applying the principles of the CiRcular Economy and sAniTary and Environmental security - RECREATE coordinated R&D&i project (PID2020-114315RB-C21 and PID2020-114315RB-C22) funded by the Ministry of Science and Innovation and the National Research Agency (MCIN/AEI/10.13039/501100011033).

- **Study the optimal operating conditions of both the Hydrothermal Carbonization (HTC) process and the Anaerobic Digestion (ADn), in order to maximize the valorization of the organic matter and nutrients present in the products obtained (hydrochar, liquid fraction, digestate , biogas).**
- **Study the (LFHTC) on its anaerobic codigestion with WWTP sludge, as well as the effect on the effect of recirculation of the liquid fraction quality of the streams obtained.**
- **Analyze the potential of the treatment scheme to remove pathogenic microorganisms, emerging contaminants and antibiotic-resistant genes.**
- **Compare the proposed treatment scheme with conventional treatment, considering health safety, economic and environmental aspects.**

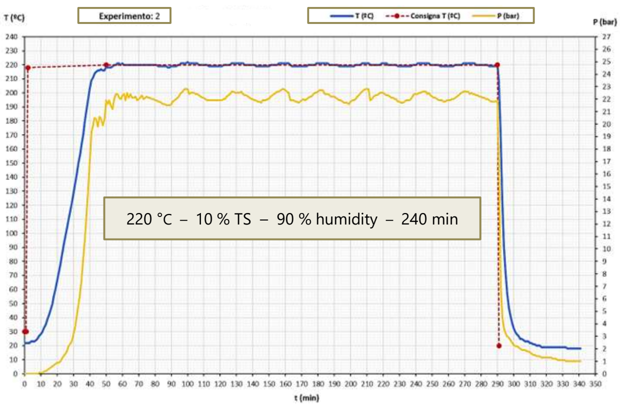
6. HTC



Treatment scheme proposed in the RECREATE project for the recovery of resources and energy, from the integration of anaerobic digestion and HTC processes

6. HTC

Hydrothermal carbonization assays



Temperature (T) and pressure (P) profile vs. time (t) in the HTC reactor.

Warm-up time

47 - 63 min

(180 - 230 °C)

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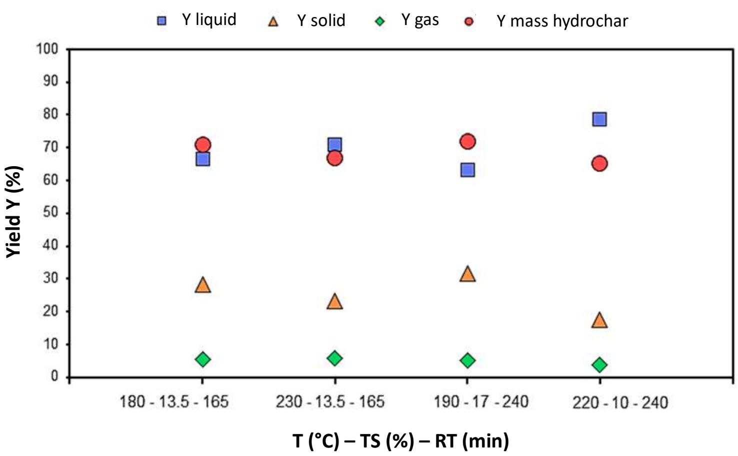
6. HTC



The HTC process allows a **reduction of more than 70%** in the generation of biosolids and favors the dehydration of sewage sludge.

Effect of temperature (T), total solids (TS) and residence time (RT) on the yields of the final products of the HTC process (hydrochar, liquid fraction and gas).

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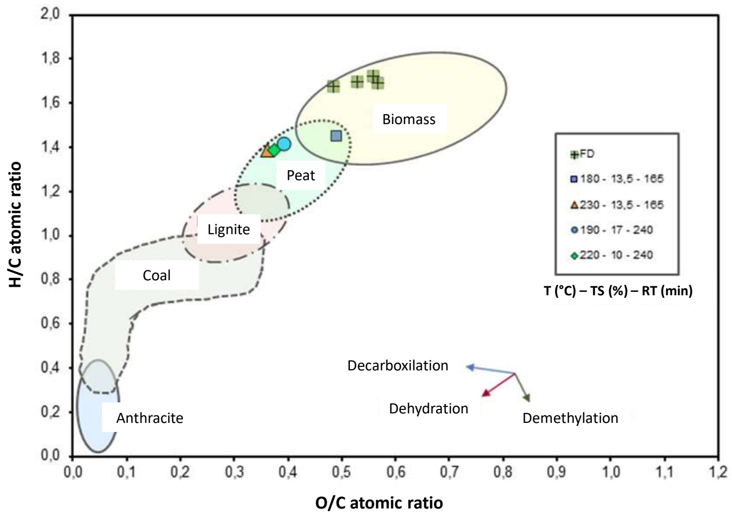
6. HTC



HYDROCHAR ≈ PEAT

C/N (220°C - 4h)

DF: 9,24
HC: 19,37
↑ **50 %**

Van Krevelen diagram for dewatered feed (DF) and solid hydrochar produced at different temperatures (T), total solids (TS) and residence times (RT).

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6. HTC

Liquid fraction

Parameters	FL-180	FL-230
pH	7,74	8,54
COD_S (mgO_2/L)	37353	38585
TOC (mgC/L)	37626	36321
N_T (mgN/L)	3640	3150
$N\text{-}NH_4^+$ (mgN/L)	2858	3144
$P\text{-}PO_4^{3-}$ (mgP/L)	347	274
Conductivity (mS/cm)	10,82	17,80

Anaerobic digestion

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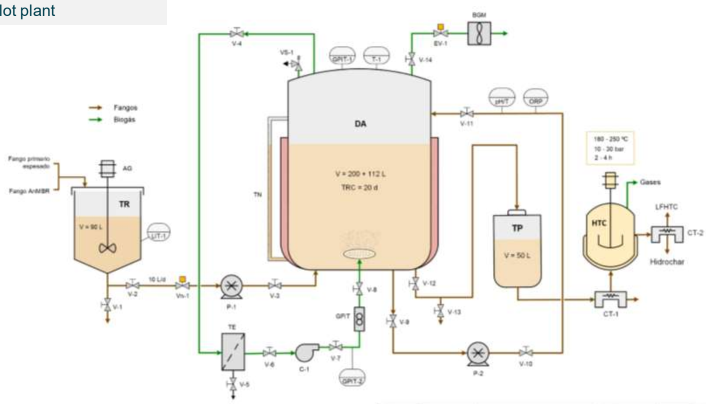
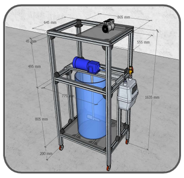
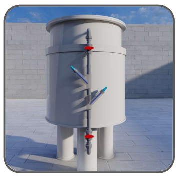
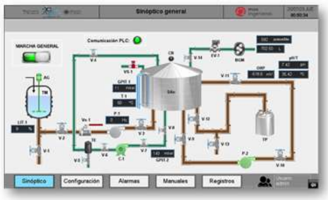
6. HTC

Design, construction and start-up of the anaerobic digestion pilot plant









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7

Reclaimed water

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7. Reclaimed water

- Study based on 200 days of operation of a demonstration plant of tertiary treatment by UF.
- Operation conditions:
  - J: 27.6-39.2 LMH
  - Membrane sparging: 0.2-1.3 $Nm^3 \cdot m^{-2} \cdot h^{-1}$

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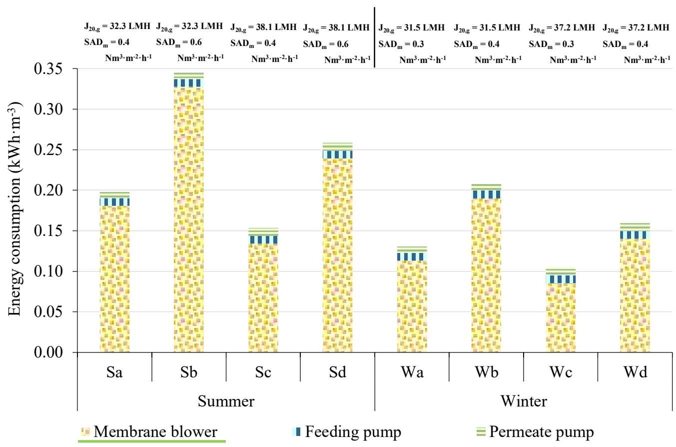
7. Reclaimed water

- Energy consumption: 0.239±0.083 $kWh \cdot m^{-3}$ in summer and 0.151±0.044 $kWh \cdot m^{-3}$ en winter.
- Main contributor → membrane socuring: 82-95 %.



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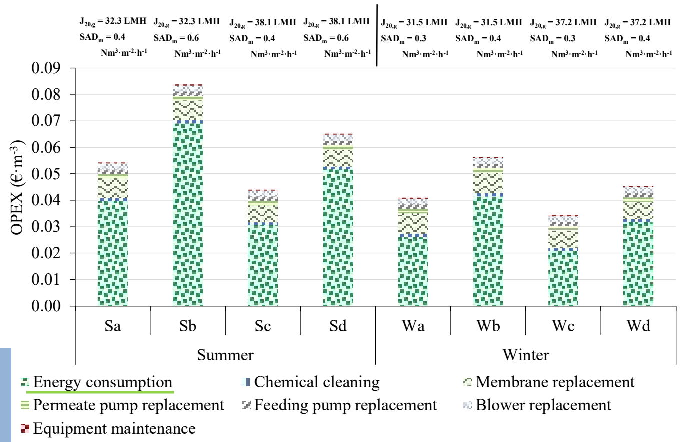
7. Reclaimed water

- **OPEX is higher in summer (0.084 €·m^{-3}) tan in Winter (0.044 €·m^{-3}).**
- **Energy consumption → main cost within OPEX (67-76 %).**
- **Optimization of OPEX → reducing membrane scouring without increasing fouling propensity (e.g., improved buck-washes).**

Melgarejo et al., (2016): 0.034 €·m^{-3} for UF and 0.007 m^{-3} for UV.
Akhoundi and Nazif (2018): 0.146-0.570 €·m^{-3} for UF y+and 0.006 €·m^{-3} for UV.
Hernández-Chover et al. (2022): 0.184 €·m^{-3} for UF.



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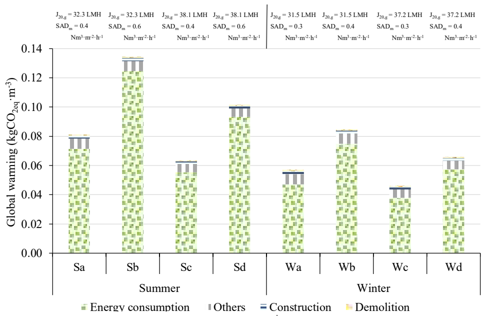
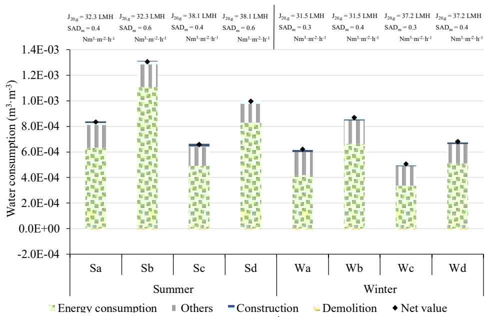
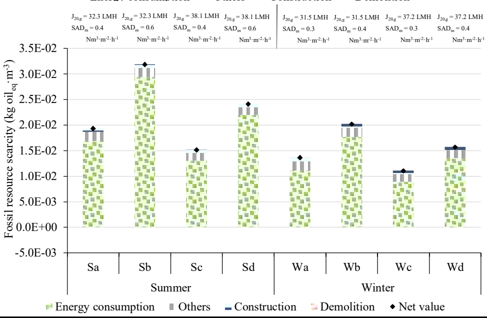
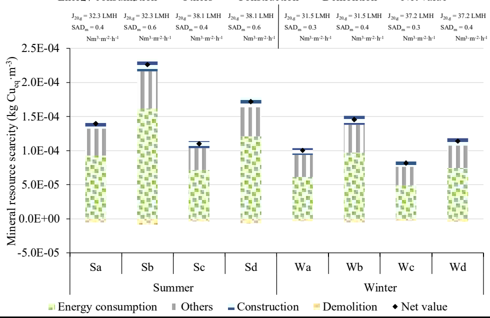
7. Reclaimed water









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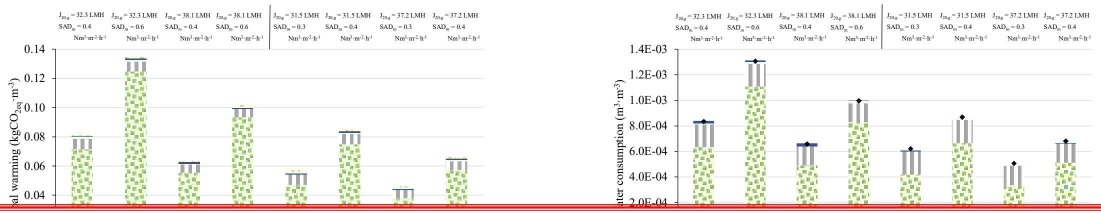
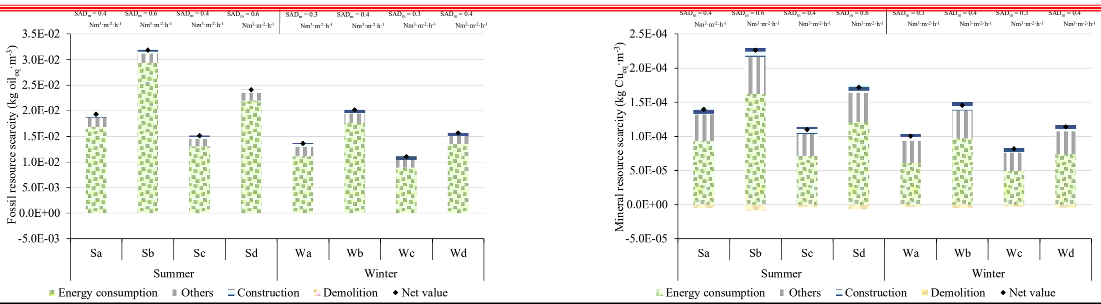
7. Reclaimed water



Energy consumption is the factor that contributes the most in all the categories studied.
Environmental loads occur during the operation phase.
The construction phase has a small influence only in the MRE category.
The demolition phase is negligible in all categories.



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7. Reclaimed water

Parameter	Unit	Effluent Mean±SD			Regulation (EU) 2020/741	Spanish royal decree 1620/2007
E. coli	CFU·100 mL^{-1}	0	±	0	≤ 10	≤ 100
BOD$_5$	mg·L^{-1}	4.2	±	2.8	≤ 10	n.a.
SS	mg·L^{-1}	3	±	2	≤ 10	≤ 20
Turbidity	NTU	1.0	±	0.6	≤ 5	≤ 10
Conductivity	dS·m^{-1}	1.7	±	0.3	n.a.	≤ 3.0
Metals, transition metals and metalloids						
B	mg·L^{-1}	1.41E-01	±	4.08E-02	n.a.	≤ 0.5
As	mg·L^{-1}	8.26E-04	±	1.14E-04	n.a.	≤ 0.1
Be	mg·L^{-1}	2.90E-05	±	4.25E-05	n.a.	≤ 0.1
Cd	mg·L^{-1}	7.66E-05	±	5.97E-05	n.a.	≤ 0.01
Co	mg·L^{-1}	2.96E-04	±	1.16E-04	n.a.	≤ 0.05
Cr	mg·L^{-1}	2.70E-03	±	3.87E-03	n.a.	≤ 0.1
Cu	mg·L^{-1}	3.03E-02	±	2.90E-02	n.a.	≤ 0.2
Mn	mg·L^{-1}	1.61E-02	±	8.78E-03	n.a.	≤ 0.2
Mo	mg·L^{-1}	2.43E-03	±	9.87E-04	n.a.	≤ 0.01
Ni	mg·L^{-1}	3.70E-02	±	3.90E-02	n.a.	≤ 0.2
Se	mg·L^{-1}	9.64E-04	±	4.74E-04	n.a.	≤ 0.02
V	mg·L^{-1}	7.07E-04	±	3.75E-04	n.a.	≤ 0.1

- **The permeate meets the requirements to be considered Class A according to Regulation (EU) 2020/741.**

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7. Reclaimed water

Parameter	Unit	Effluent Mean±SD	Regulation (EU) 2020/741	Spanish royal decree 1620/2007
E. coli	CFU·100 mL^{-1}	0 ± 0	≤ 10	≤ 100
BOD_5	mg·L^{-1}	4.2 ± 2.8	≤ 10	n.a.
SS	mg·L^{-1}	3 ± 2	≤ 10	≤ 20
Turbidity	NTU	1.0 ± 0.6	≤ 5	≤ 10
Conductivity	dS·m^{-1}	1.7 ± 0.3	n.a.	≤ 3.0
Metals, transition metals and metalloids				
B	mg·L^{-1}	1.41E-01 ± 4.08E-02	n.a.	≤ 0.5
As	mg·L^{-1}	8.26E-04 ± 1.14E-04	n.a.	≤ 0.1
Be	mg·L^{-1}	2.90E-05 ± 4.25E-05	n.a.	≤ 0.1
Cd	mg·L^{-1}	7.66E-05 ± 5.97E-05	n.a.	≤ 0.01
Co	mg·L^{-1}	2.96E-04 ± 1.16E-04	n.a.	≤ 0.05
Cr	mg·L^{-1}	2.70E-03 ± 3.87E-03	n.a.	≤ 0.1
Cu	mg·L^{-1}	3.03E-02 ± 2.90E-02	n.a.	≤ 0.2
Mn	mg·L^{-1}	1.61E-02 ± 8.78E-03	n.a.	≤ 0.2
Mo	mg·L^{-1}	2.43E-03 ± 9.87E-04	n.a.	≤ 0.01
Ni	mg·L^{-1}	3.70E-02 ± 3.90E-02	n.a.	≤ 0.2
Se	mg·L^{-1}	9.64E-04 ± 4.74E-04	n.a.	≤ 0.02
V	mg·L^{-1}	7.07E-04 ± 3.75E-04	n.a.	≤ 0.1

- The permeate meets the requirements to be considered Class A according to Regulation (EU) 2020/741.
- **The permeate would also meet the requirements of RD 1620/2007 regarding metal content for use as irrigation water in its most strict category.**

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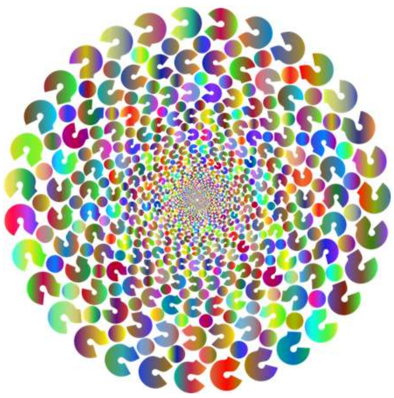
Questions

Thank you for your attention

Questions?



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Séminaires du réseau REUSE d'INRAE

Opportunities and challenges for resource recovery from urban wastewater

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