CHANIA 2023

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Options for the reuse of municipal wastewater in the Antofagasta mining district: a 3-E analysis for a nearly-energy positive WWTP

Politecnico di Torino
1859

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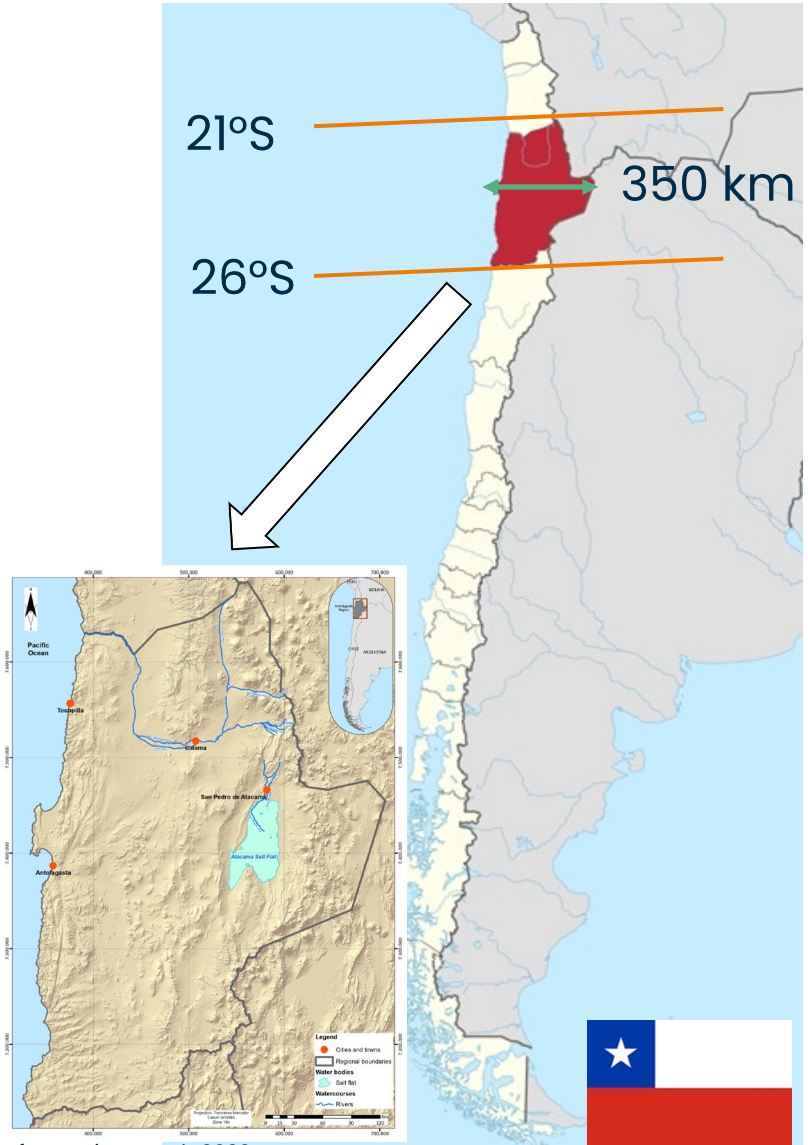
Water management: key factors

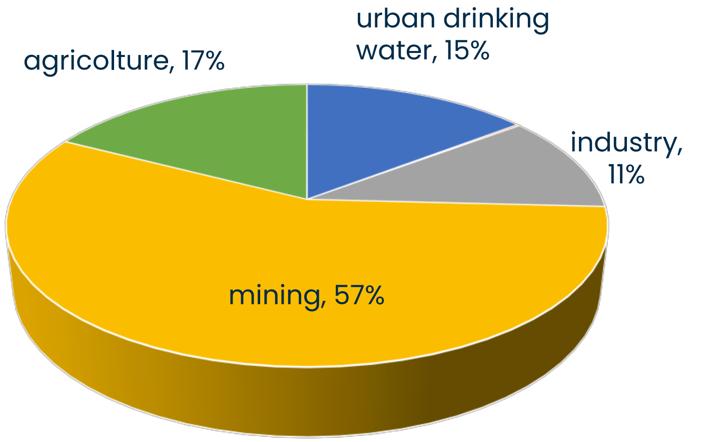


from Prieto et al., 2022

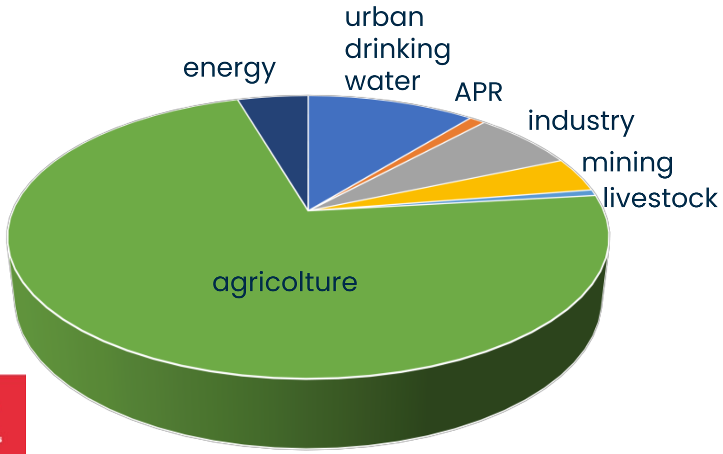
High water stress

- ❑ Hydrology and climate
- ❑ Water quality
- ❑ Mining activity

H2020-MSCA-RISE-2018
REMIND Project



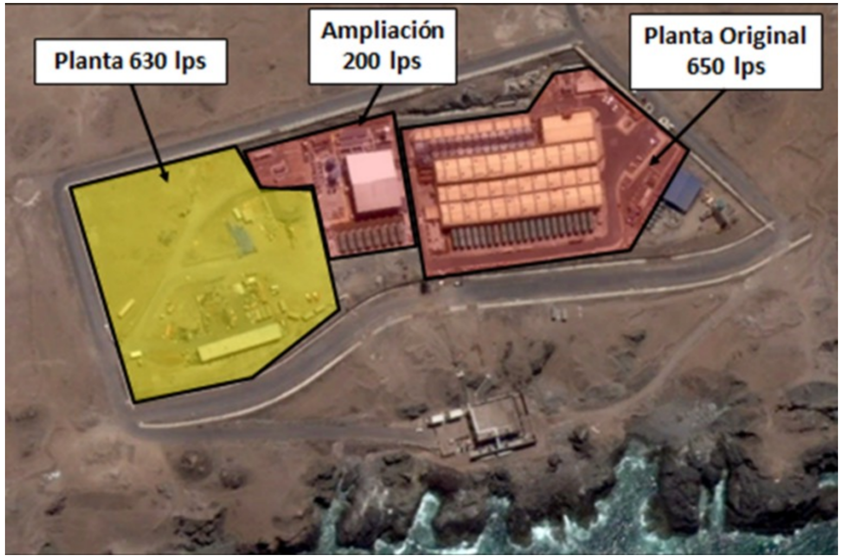
Antofagasta, $266 \cdot 10^9$ m^3/y

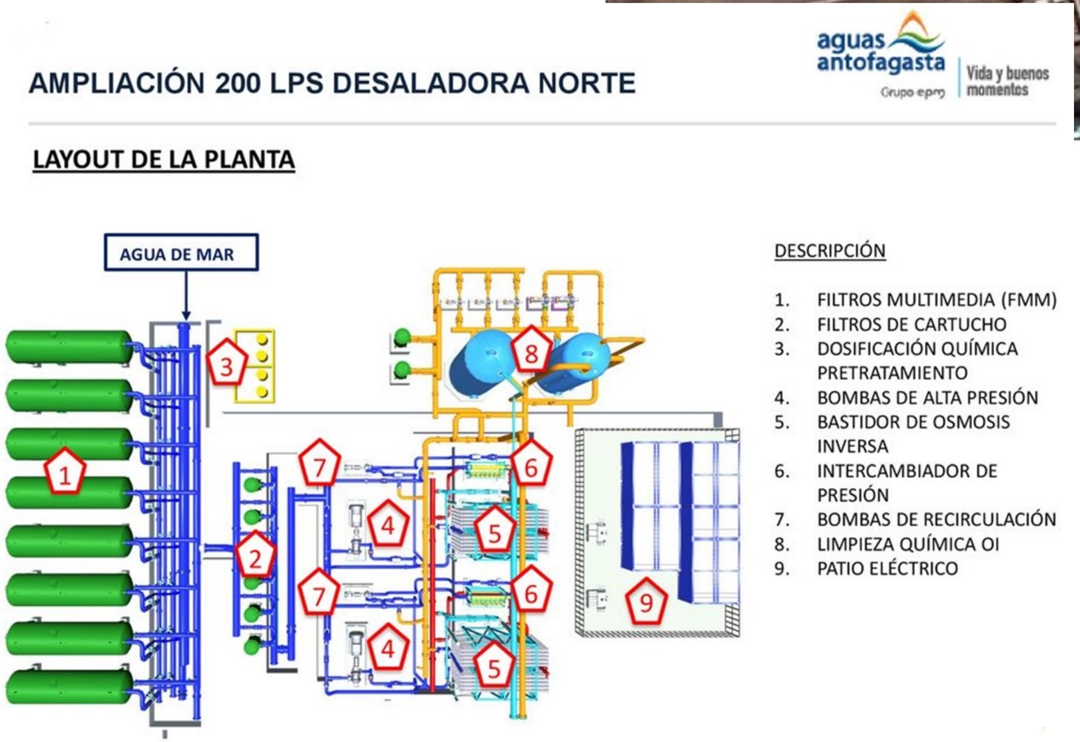


Chile, $10910 \cdot 10^9$ m^3/y

Dirección General de Aguas
Ministerio de Obras Públicas
Gobierno de Chile

Is desalination a solution?





Victór-Gutiérrez, 2017

Present situation

Preliminary treatments

90%

discharge into the Ocean

10%

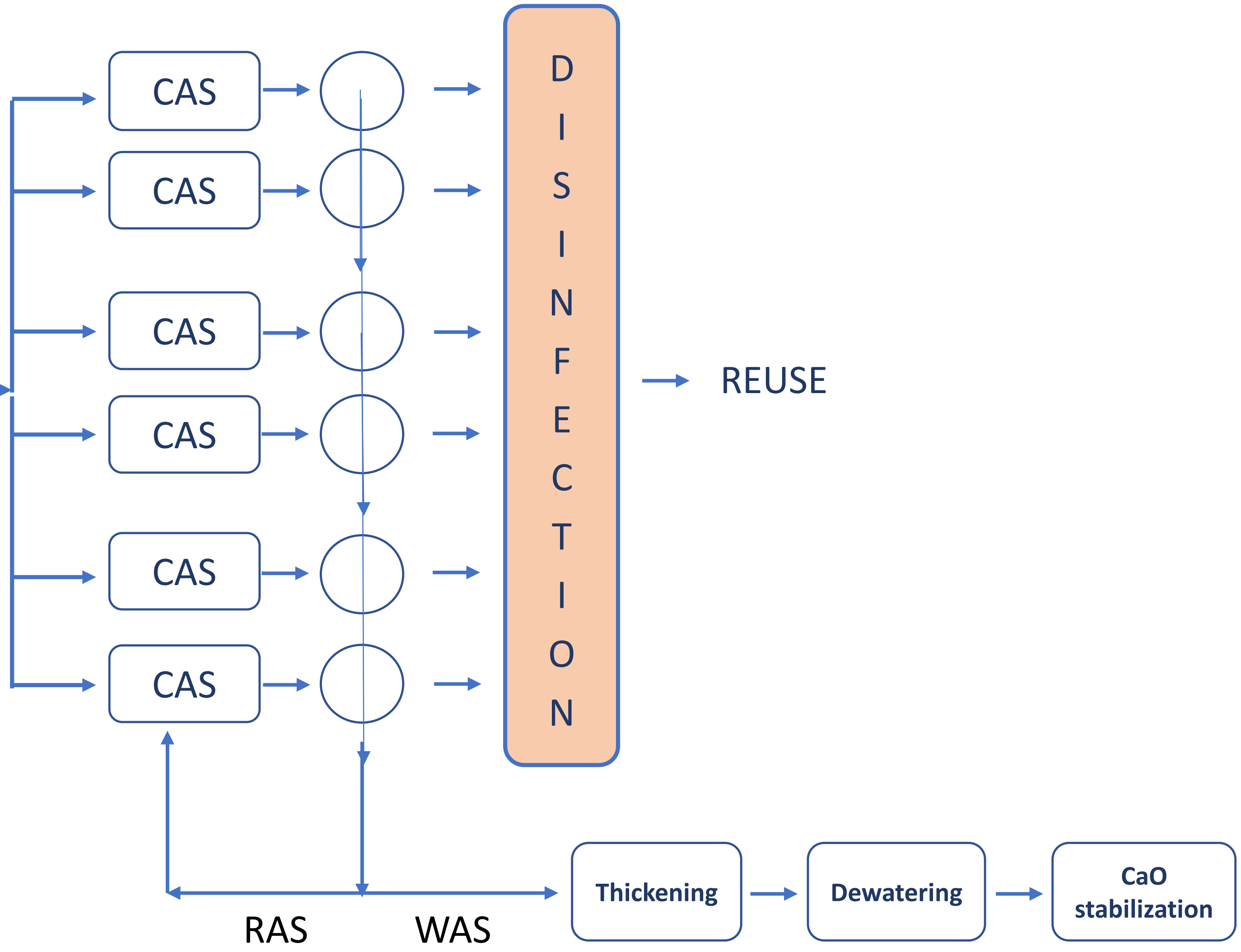
reuse for industrial purposes

CAS
120 L/s

Future situation (→ 2025)

Treatment capacity,
900 L/s

3 modules, 300 L/s each



WASTEWATER QUALITY

Parameter	Unit	After Preliminary Treatments	D.S. 90/2000 Threshold Values (*)
Temperature	°C	>20	N.A.
pH		7.7	6–9
Fats and oils	mg/L	75	20
TSS	mg/L	225	80
BOD_5	mg/L	242	35
TKN	mg/L	51	50
TP	mg/L	5	10
Chloride	mg/L	999	N.A.
Alkalinity	mg/L as $CaCO_3$	286	N.A.
Total coliforms	CFU/100 mL	N.A.	1000

Notes: TSS, total suspended solids; CFU, colony-forming unit. (*) D.S.90/2000 of MINSEGPRES "Establece norma de emisión para la regulación de contaminantes asociados a las descargas de residuos líquidos a aguas marinas y continentales superficiales".

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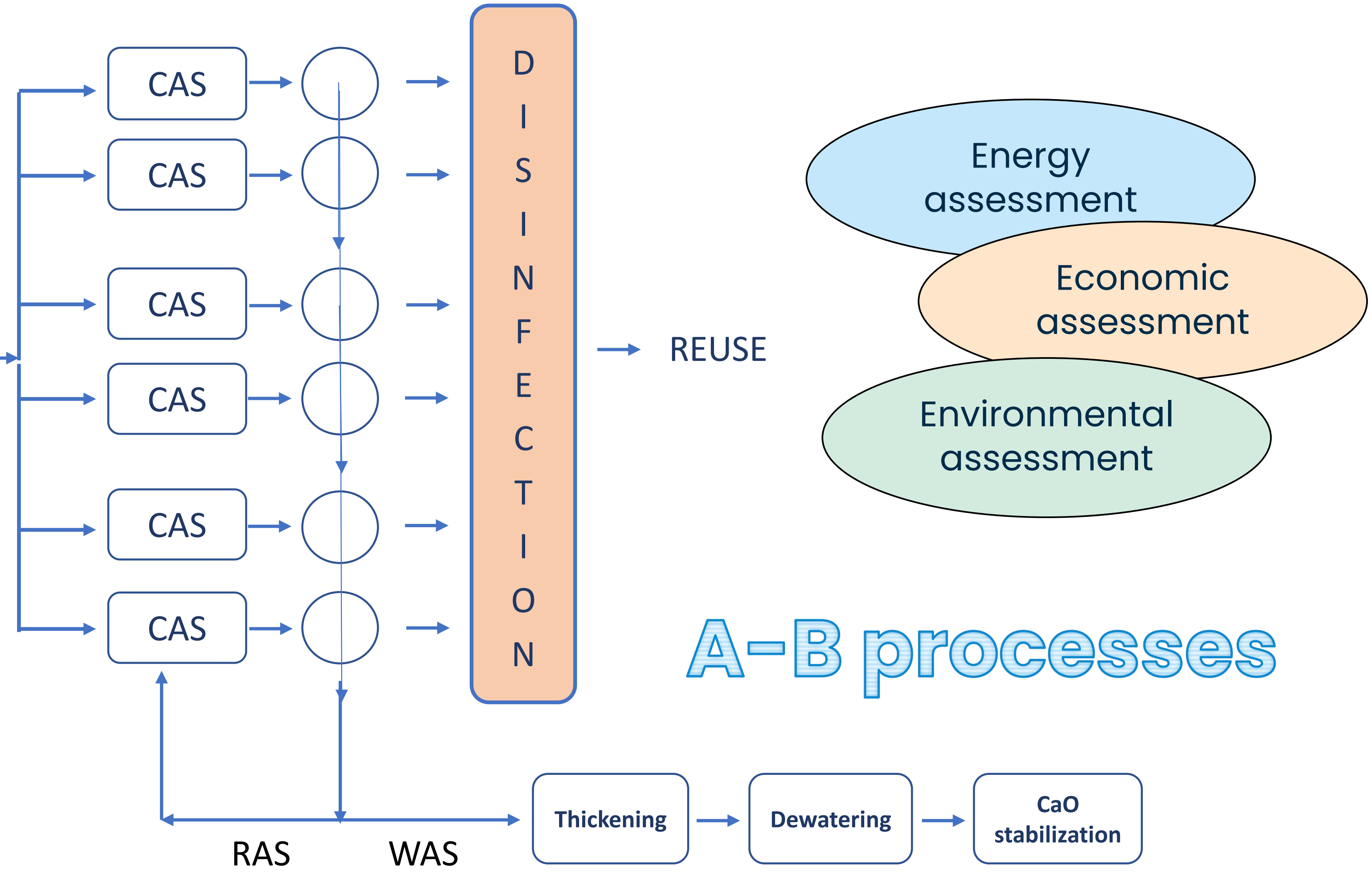

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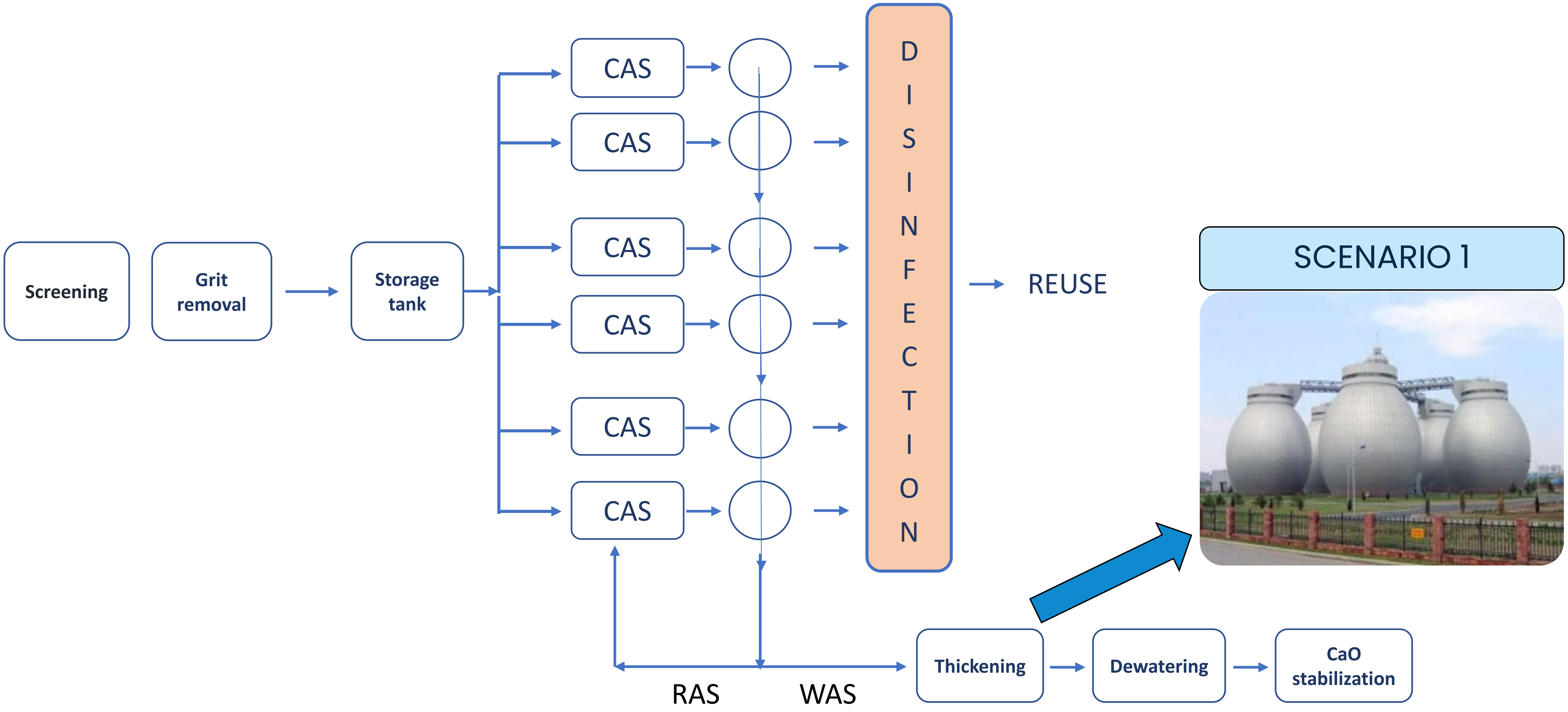
Towards a nearly-positive WWTP



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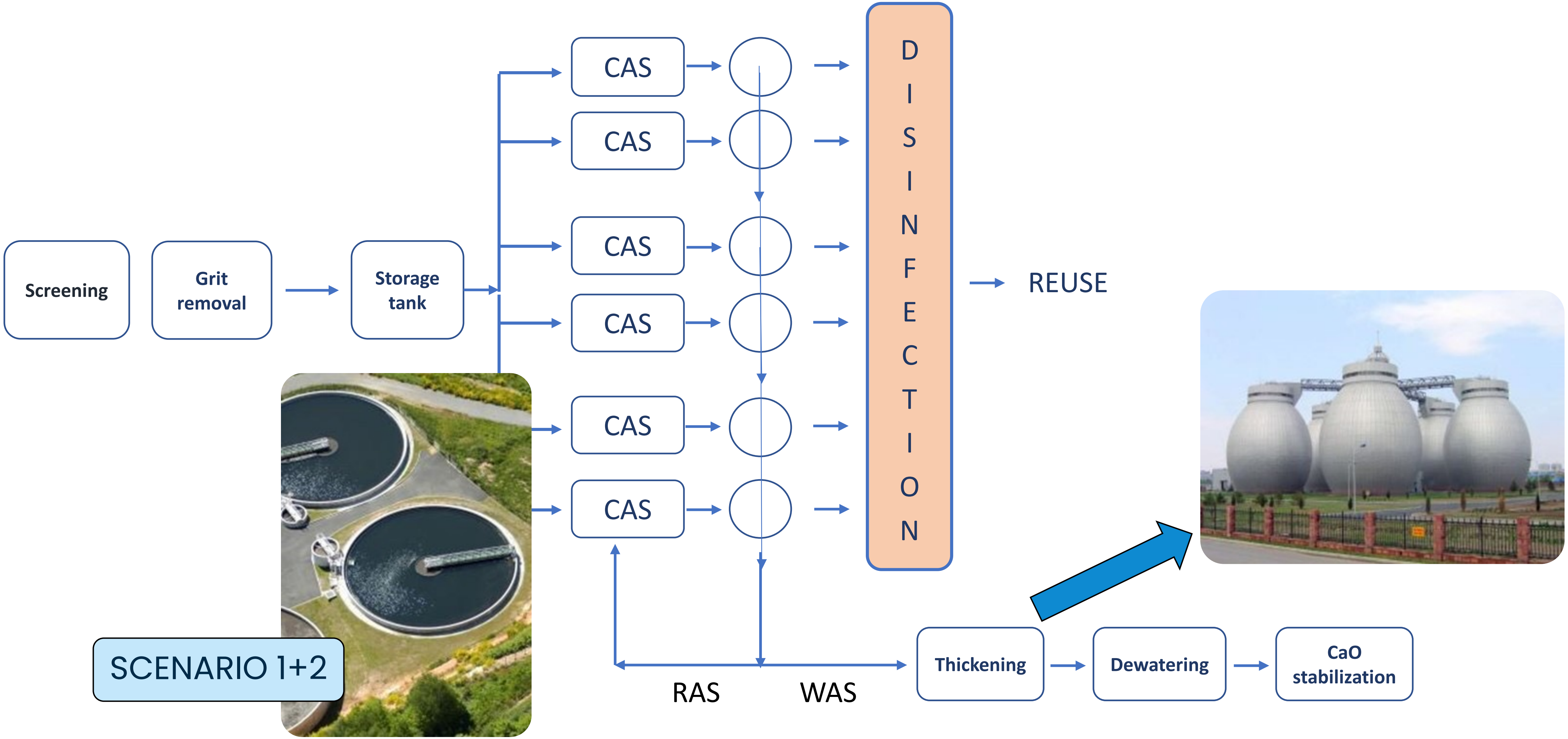
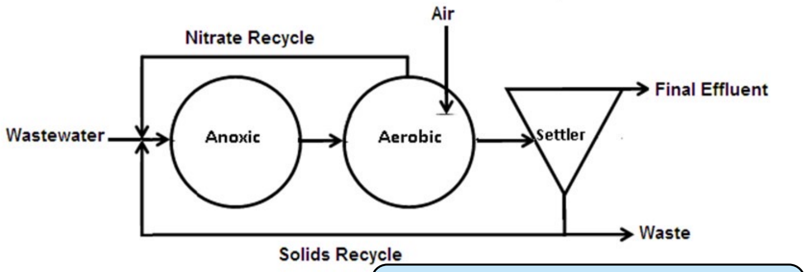


Towards a nearly-positive WWTP



SCENARIO 1+2+3

Screening → Grit removal → Storage tank → CAS (×6) → DISINFECTION → REUSE

RAS

WAS → Thickening → Dewatering → CaO stabilization

SRT = 7 days

DO = 2 mg/L

%TSS (PS & WAS) = 5%

HRT (AD process) = 20 days

Methodology

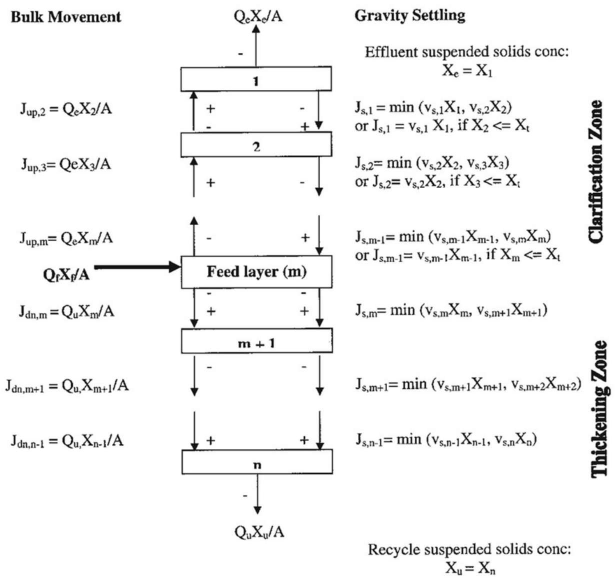
- Ideal zero-dimension removal efficiency model (primary settling, thickening, dewatering)
- Activated Sludge Model n.3, ASM3 (biological processes)
- Takacs one-dimension clarifier model (secondary settling)
- Stoichiometric approach (anaerobic digestion)

Table 1. Process kinetics and stoichiometry for heterotrophic bacterial growth in an aerobic environment

Continuity →

Mass Balance ↓

Component → i / j Process ↓	1 X_B	2 S_S	3 S_O	Process Rate, ρ_j $[ML^{-3}T^{-1}]$
1 Growth	1	$-\frac{1}{Y}$	$-\frac{1-Y}{Y}$	$\frac{\hat{\mu} S_S}{K_S + S_S} X_B$
2 Decay	-1		-1	bX_B
Observed Conversion Rates $ML^{-3}T^{-1}$	$r_i = \sum_j r_{ij} = \sum_j \nu_{ij}\rho_j$			Kinetic Parameters: Maximum specific growth rate: $\hat{\mu}$; Half-velocity constant: K_S; Specific decay rate: b
Stoichiometric Parameters: True growth yield: Y	Biomass $[M(COD)L^{-3}]$	Substrate $[M(COD)L^{-3}]$	Oxygen (negative COD) $[M(-COD)L^{-3}]$	



PROCESS CALCULATION

EQUIPMENT DESIGN

ELECTRICITY DEMAND CALCULATION

EQUIPMENT COST CALCULATION

INVESTMENT PROFITABILITY ASSESSMENT

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1-i)^t}$$

Methodology

Unit of Process	Parameter and Design Criteria	Equation
Primary settlers	Wastewater design flow rate, Q_{WW} Surface-loading rate, SLR	Primary settler area $S_{PS} = \frac{Q_{WW}}{SLR}$
Anaerobic digesters	Sludge average flow rate, Q_{sludge} HRT anaerobic digesters V_{work}/V_{tot} ratio	Digester—working volume $V_{work} = Q_{sludge} \cdot HRT_{anaer}$ Digester—total volume $V_{tot,AD} = \frac{V_{work}}{\frac{V_{work}}{V_{tot}} ratio}$
CHP unit	Methane flowrate, Q_{CH4} Methane LHV, LHV_{CH4} Electric efficiency, η_{el} Thermal efficiency, η_{th}	Electric power $W_{CHP,el} = \eta_{el} \cdot LHV_{CH4} \cdot Q_{CH4}$ Thermal power $W_{CHP,th} = \eta_{th} \cdot LHV_{CH4} \cdot Q_{CH4}$
Gasometer	Biogas flowrate, Q_b HRT gasometer	Gasometer volume $V_G = Q_b \cdot HRT_{gasometer}$
Back-up boiler	CHP unit thermal power, $W_{CHP,th}$	$W_{BuB} = 0.8 \cdot W_{CHP,th}$

Piece of Equipment	PEC Correlation ($)	Unit	Year	CEPCI	ER
Primary settler	$\frac{1}{18} \cdot (2630 \cdot S_{PS}^{0.678} + 6338 S_{PS}^{0.340})$	m^2	1998	389.5	1.82
Anaerobic digester	$840221.5 \cdot \left(\frac{V_{tot,AD}}{3000}\right)^{0.8}$	m^3	2016	541.7	1.31
Desulfurization	$\frac{1}{1.12} \cdot 15974.13 \cdot Q_{biogas}$	Nm^3/h	2011	585.7	1.21
Demister	$0.01 \cdot cost\ desulfurization$	$	2011	585.7	1.21
Gasometer	$\frac{1}{1.12} \cdot 40 \cdot V_G$	m^3	2012	584.6	1.21
Biogas blower	$91562 \cdot \left(\frac{W_{BuB}}{455}\right)^{0.67}$	kWe	2013	567.3	1.21

PROCESS CALCULATION

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$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1-i)^t}$$

Intermediate results

MAIN OUTPUTS OF THE SIMULATION MODELS

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3	
				anoxic	oxic
MLSS (mg/L)	6775	6775	3600	3612	3610
OD (kg/d)	6049	6049	4675	0	3951
α factor (dimensionless)	0.36	0.36	0.39	-	0.41
NH_4-N (mg/L)	1	1	1	25	1
NO_3-N (mg/L)	38	38	43	2	24
WAS (kg TSS/d)	37,177	37,177	19,755	19,815	
PS (kg TSS/d)	-	-	22,363	22,363	
Stabilized sludge/digestate (kg TSS/d)	48,910 *	33,140	30,310	30,200	
Stabilized sludge/digestate, 25% TSS (ton/d)	195.6	132.6	121.2	120.8	

Note: * comprehensive of the CaO addition.

MAIN OUTPUTS OF THE SIMULATION MODELS

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Biogas production (Nm^3/d)	0	3538	9333	9535
Methane production (Nm^3/d)	0	2229	5880	6007
Renewable thermal energy (kW)	0	388	1025	1047
Renewable electric energy (kW)	0	370	976	997

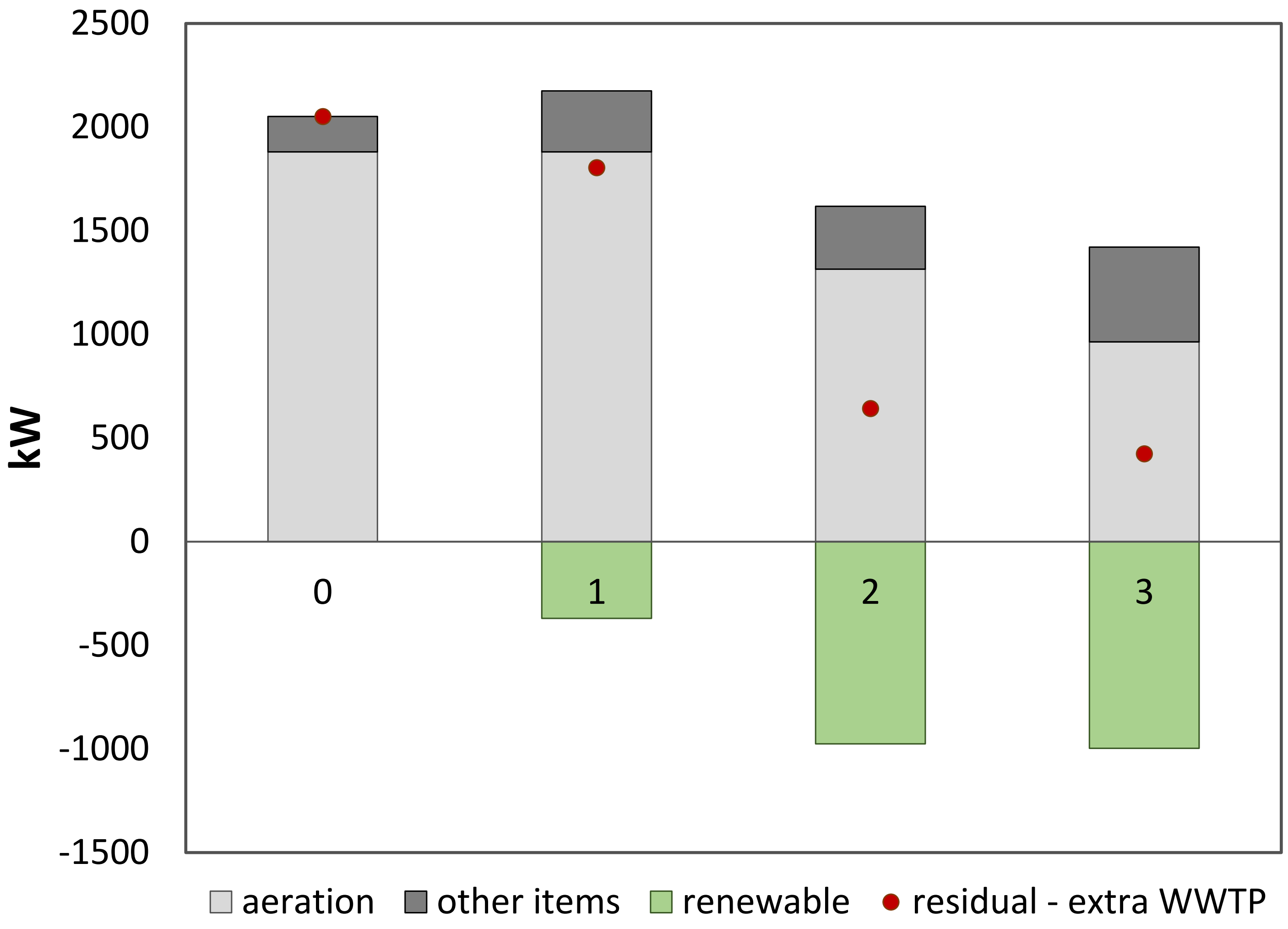
OUTPUTS OF THE EQUIPMENT DESIGN

Pieces of Equipment	Scenario 1	Scenario 2	Scenario 3
Primary settlers, area (m^2)	0	1944	1944
Primary settlers, number	0	6	6
Primary settlers, diameter (m)	0	20	20
Anaerobic digesters, volume (m^3)	18,700	21,000	21,100
Gasometer, volume (m^3)	660	1745	1778
Back-up boiler, power (W)	308	818	837
Heat exchanger, area (m^2)	17.7	20	20
Digestate post-thickener, area (m^2)	375	420	420
Digestate post-thickener, volume (m^3)	750	841	841

OUTPUTS OF THE EQUIPMENT COST ASSESSMENT

Pieces of Equipment ($)	Scenario 1	Scenario 2	Scenario 3
Anaerobic digesters	3,988,000	4,370,000	4,370,000
Biogas desulfurization unit	14,000	18,500	18,500
Gravel filter demister	1400	1850	1850
Gasometer	29,000	75,600	77,000
CHP unit	1,450,000	3,824,000	3,906,000
Heat exchanger	204,000	221,000	221,000
Flare stack	58,000	105,500	106,500
Back-up boiler	61,000	159,500	163,000
Digestate post-thickener	61,500	61,500	61,500
Primary settlers	0	815,750	815,750
Total	45,447,400	49,234,200	49,332,100
Increment vs. Scenario 0	+14.8%	+24.4%	+24.6%

Energy assessment



Energy consumption from external sources

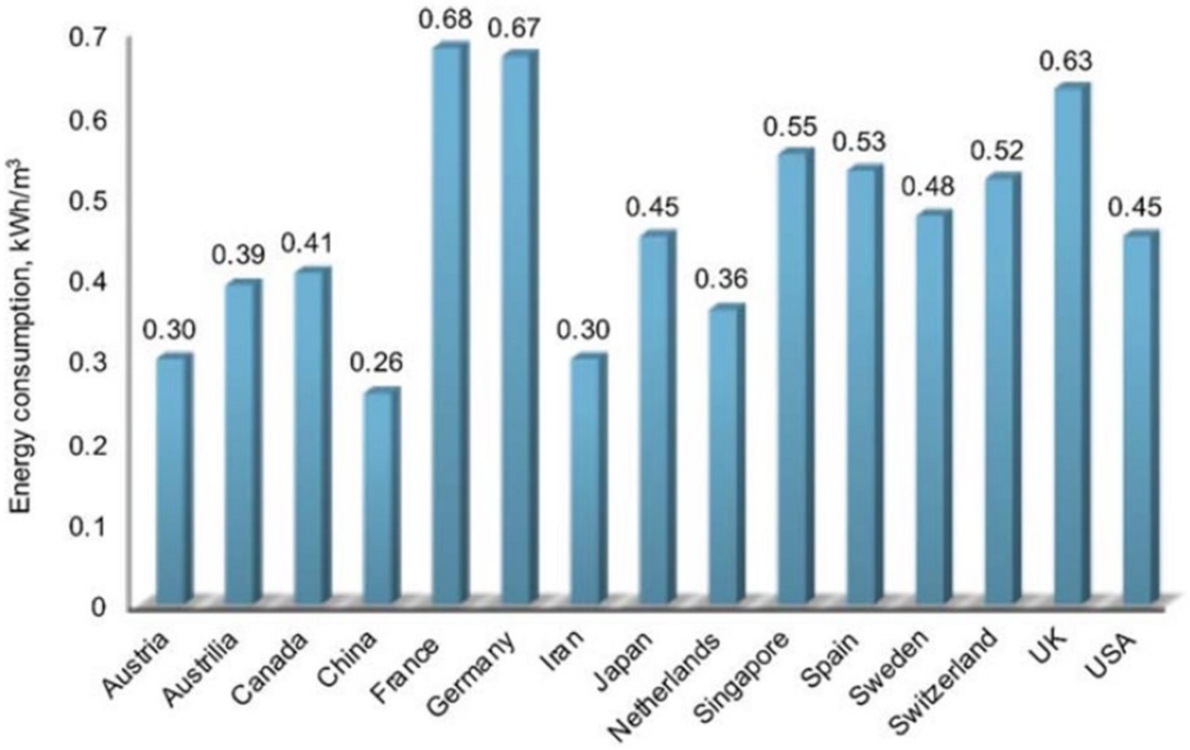
$EC0 = 0.63\ kWhe/m^3$

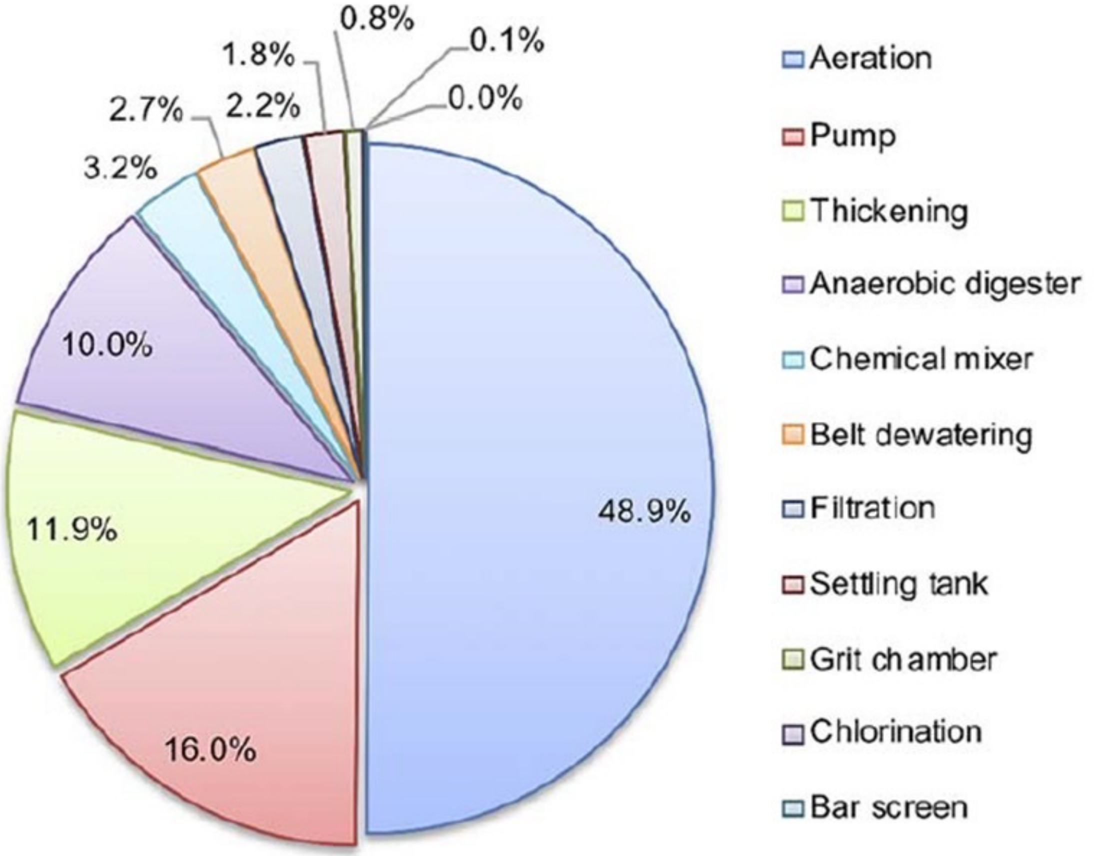
$EC1 = 0.56\ kWhe/m^3$

$EC2 = 0.20\ kWhe/m^3$

$EC3 = 0.13\ kWhe/m^3$

Energy consumption in WWTPs

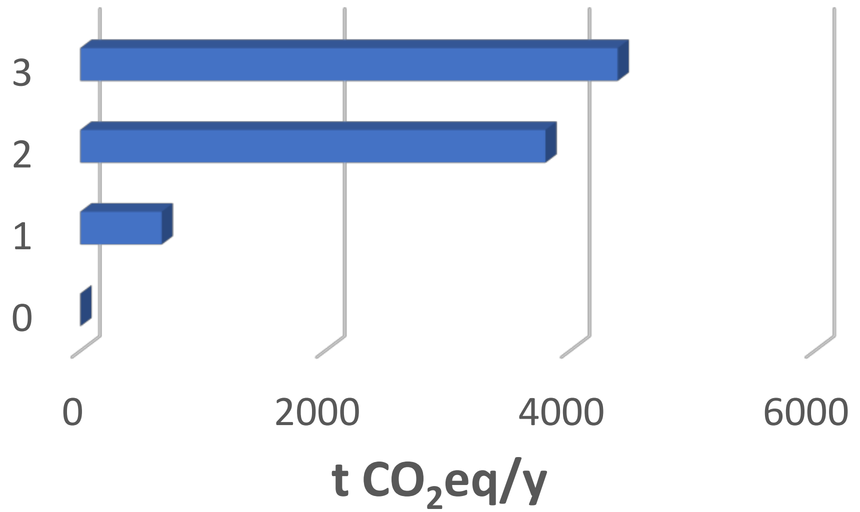




Geographic distribution of energy consumption in WWTPs
(from Liu et al., 2019)

Economic & environmental assessments

Avoided CO_2 emissions



0.308 kg CO_2eq/kWhe
Chilean energy mix

DIGESTATE DESTINATION

IRR1	0.37
IRR2	0.34
IRR3	0.36

IRR1	0.13
IRR2	0.21
IRR3	0.24

Conclusions

The results of the study demonstrated that:

1. The introduction of an AD process (Scenario 1) to stabilize the sludge before reuse in agriculture or disposal in a landfill could save approx. 12% of the electric energy supplied to the WWTP, with an inherent reduction in CO_2 eq emission of 660 tons/y;
2. The introduction of an AD process and of a section of primary sedimentation (Scenario 2) could reduce the amount of electric energy supplied to the WWTP from external sources to only 30% of the WWTP original scheme (Scenario 0), thus avoiding the emission of 3800 tons CO_2 eq/y. Such a benefit was made possible because of the significant increase in the produced renewable energy (+260% with respect to Scenario 1) and the decrease in the energy demand due to the aeration process (-30% with respect to Scenarios 0 and 1);
3. The implementation of an oxic-anoxic partition of the CAS tank, other than AD and primary sedimentation, (Scenario 3) allowed the WWTP to reduce its electric energy demand from external sources to only 20% of that of Scenario 0, thus avoiding the emission of 4390 tons CO_2 eq/y. The present requirement on the nitrogen concentration in the wastewater to be discharged or reused for mining activities does not require the presence of nitrification–denitrification processes. However, a nitrification-denitrification scheme makes it possible to consume an aliquot of the residual biodegradable organic substance at no free oxygen expenses, thus saving the corresponding aliquot of electric energy necessary for the aeration process.

water

MDPI

Article

Water-Energy Nexus in the Antofagasta Mining District: Options for Municipal Wastewater Reuse from a Nearly Energy-Neutral WWTP

Giuseppe Campo [1,*], Barbara Ruffino [1,2,*], Arturo Reyes [3] and Mariachiara Zanetti [1]

March, 2023

H2020-MSCA-RISE-2018
REMIND Project

MDPI

International Journal of Environmental Research and Public Health

Review

Drinking Water Supply in the Region of Antofagasta (Chile): A Challenge between Past, Present and Future

Barbara Ruffino [1,2,*], Giuseppe Campo [1], Dafne Crutchik [3], Arturo Reyes [4] and Mariachiara Zanetti [1]

November, 2022

CHANIA 2023

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Thanks for your kind attention!

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