

Supplementary material

Multi-objective comparison of conventional and emerging wastewater treatment processes based on simulation to reduce greenhouse gas emissions

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Texts

Text S1 Accounting boundary

The boundary scope for carbon emission accounting in each process of this study includes direct and indirect emissions during wastewater treatment and sludge treatment. The accounting boundary is shown in the Fig. S2. Subdivided into: (1) direct CO₂ emissions during anaerobic treatment, (2) direct CO₂ emissions during aerobic treatment, (3) direct N₂O emissions during anoxic treatment, (4) direct CH₄ emissions during wastewater treatment, (5) indirect carbon emissions generated by external carbon sources, (6) indirect carbon emissions generated by power consumption, (7) indirect carbon emissions generated by chemicals production, (8) indirect CH₄ emissions during wastewater discharge, (9) indirect N₂O emissions during wastewater discharge, and (10) direct GHG emissions during sludge anaerobic digestion.

Text S2 Accounting Methods

The carbon emission accounting method in this study combined emission factor method and mass balance method, and divided the carbon emissions of each process into multiple carbon emission sources for calculation. The calculation of each emission source is as follows (Eq.(S1-S13)):

(1) Direct emissions of fossil fuel CO₂ from anaerobic treatment

$$M_{CO_2, Bio+Fos} = 0.27 Q \cdot (COD_o - COD_e) \cdot 10^{-3} + 0.58 Q \cdot HRT \cdot MLVSS \cdot K_d \cdot 10^{-3} \quad (S1)$$

$$M_{CO_2, Ana} = FCF \cdot M_{CO_2, Bio+Fos} \quad (S2)$$

In the formula:

$M_{CO_2, Bio+Fos}$ —Total direct CO₂ emissions from biological and fossil sources, kgCO₂eq/d;

Q —anaerobic tank influent flow, m³/d;

COD_o —COD concentration in the influent of anaerobic tank, mg COD/L;

COD_e —COD concentration in the effluent of anaerobic tank, mg COD/L;

HRT —anaerobic tank hydraulic retention time, d;

$MLVSS$ —average concentration of mixed liquid volatile suspended solids, mg/L;

K_d —attenuation coefficient, 0.05 d⁻¹;

$M_{CO_2,Ana}$ —direct CO₂ emissions from anaerobic treatment process, kgCO₂eq/d;

FCF—the proportion of fossil sources in the direct CO₂ emissions, take 10%.

(2) Direct emissions of CO₂ from aerobic treatment

$$M_{CO_2,Aer} = [(1.1a \cdot Q - 1.1c \cdot y \cdot Y) \cdot (COD_o - COD_e) \cdot 10^{-3} + 1.947 Q \cdot HRT \cdot MLVSS \cdot K_d \cdot 10^{-3}] \cdot FCF \quad (S3)$$

In the formula:

$M_{CO_2,Aer}$ —direct CO₂ emissions from aerobic treatment, kgCO₂eq/d;

Q —aerobic tank influent flow, m³/d;

a —oxygen equivalent of carbon, 1.47;

c —oxygen equivalent of bacterial cells, 1.42;

Y —aerobic tank sludge yield coefficient, kg MLVSS/kgBOD₅;

COD_o —COD concentration in the influent of aerobic tank, mg COD/L;

COD_e —COD concentration in the effluent of aerobic tank, mg COD/L;

HRT—aerobic tank hydraulic retention time, d;

y —MLVSS/MLSS;

$MLVSS$ —average concentration of mixed liquid volatile suspended solids, mg/L;

$MLSS$ —average concentration of mixed liquid suspended solids, mg/L;

K_d —attenuation coefficient, 0.05 d⁻¹;

FCF—the proportion of fossil sources in the direct CO₂ emissions, take 10%.

(3) Direct emission of N₂O from anoxic treatment

$$M_{N_2O} = GWP_{N_2O} \cdot \{ [Q \cdot (TN_o - TN_e) / 10^{-3}] \cdot EF_{N_2O} \cdot C_{CO_2/N_2} \} \quad (S4)$$

In the formula:

M_{N_2O} —direct emission of N₂O from anoxic treatment, kgCO₂eq/d;

GWP_{N_2O} —N₂O global warming potential value, 298;

Q —anoxic tank influent flow, m³/d;

TN_o —TN concentration in the influent of anoxic tank, mgN/L;

TN_e —TN concentration in the effluent of anoxic tank, mgN/L;

EF_{N_2O} —the amount of N converted into N₂O per unit mass, 0.05 kgN₂O-N/kgN₂-N;

C_{CO_2/N_2} —N₂O/N₂ molecular weight ratio, 44/28.

(4) Direct emission of CH₄ from wastewater treatment process

$$M_{CH_4} = [Q \cdot (COD_o - COD_e) \cdot 10^{-3} \cdot BOD/COD \cdot B_o \cdot MCF_{Treated}] \cdot GWP_{CH_4} \quad (S5)$$

In the formula:

M_{CH_4} —direct emission of CH₄ from wastewater treatment process, kgCO₂eq/d;

Q —daily wastewater influent, m³/d;

COD_o —COD concentration in the influent, mg COD/L;

COD_e —COD concentration in the effluent, mg COD/L;

BOD/COD —recommended values for regional average BOD/COD;

B_o —maximum generation capacity of CH₄, 0.6 kgCH₄/kgBOD;

$MCF_{Treated}$ —CH₄ correction factor, 0.165;

GWP_{N_2O} —CH₄ global warming potential value, 25.

(5) Indirect carbon emissions generated by external carbon sources

$$M_{CO_2,EC} = EF_{EC} \cdot M_{EC} \quad (S6)$$

In the formula:

$M_{CO_2,EC}$ —indirect carbon emissions generated by external carbon sources, kgCO₂eq/d;

EF_{EC} —emission factor for the oxidation of external carbon sources into CO₂, kgCO₂/kg;

M_{EC} —total mass of carbon source added during denitrification process, kg/d;

(6) Indirect carbon emissions from electricity consumption

$$M_{CO_2,elec} = Q \cdot Se \cdot EF_{CO_2,elec} \quad (S7)$$

In the formula:

$M_{CO_2,elec}$ —indirect carbon emissions from electricity consumption, kgCO₂eq/d;

Q —daily water volume of wastewater treatment plant, m³/d;

Se —electricity consumption for treating 1m³ of wastewater, kWh/m³;

$EF_{CO_2,elec}$ —grid emission factors, kgCO₂/kWh;

(7) Indirect carbon emissions from chemicals production

$$M_{CO_2,chemical} = W \cdot EF_{CO_2,chemical} \quad (S8)$$

In the formula:

$M_{CO_2,chemical}$ —indirect carbon emissions from chemicals production, kgCO₂eq/d;

W —daily consumption of chemicals in wastewater treatment plant, kg/d;

$EF_{CO_2,chemical}$ —CO₂ emission factors in the chemicals production, kgCO₂/kg;

(8) Indirect CH₄ emissions during wastewater discharge

$$M_{CH_4,eff} = GWP_{CH_4} \cdot (M_{COD_e} \cdot BOD/COD \cdot B_o \cdot MCF_{untreated}) \quad (S9)$$

In the formula:

$M_{CH_4,eff}$ —indirect CH₄ emissions during wastewater discharge, kgCO₂eq/d;

M_{COD_e} —COD discharge from effluent, kg/d;

BOD/COD —recommended values for regional average BOD/COD;

B_o —maximum generation capacity of CH₄, 0.6 kgCH₄/kgBOD;

$MCF_{Treated}$ —CH₄ correction factor, 0.1.

(9) Indirect N₂O emissions during wastewater discharge

$$M_{N_2O,eff} = GWP_{N_2O} \cdot (M_{TN_e} \cdot C_{CO_2/N_2} \cdot EF_{N_2O}) \quad (S10)$$

In the formula:

$M_{N_2O,eff}$ —indirect N₂O emissions during wastewater discharge, kgCO₂eq/d;

M_{TN_e} —TN discharge from effluent, kg/d;

C_{CO_2/N_2} —N₂O/N₂ molecular weight ratio, 44/28;

EF_{N_2O} —N₂O emission factors in wastewater discharge process, 0.005 kgN₂O/kgN₂.

(10) Direct GHG emissions from sludge anaerobic digestion

$$M_{CO_2,biogas} = 0.27 Q_{slu} \cdot (VSS_{o,slu-dig} - VSS_{e,slu-dig}) \cdot 10^{-3} + 0.58 Q_{slu} \cdot HRT_{slu-dig} \cdot MLVSS_{slu-dig} \cdot K_d \cdot 10^{-3} \quad (S11)$$

$$M_{CH_4,biogas} = 0.25 Q_{slu} \cdot (VSS_{o,slu-dig} - VSS_{e,slu-dig}) \cdot 10^{-3} - 0.005 Y_{dig} \cdot Q_{slu} \cdot (VSS_{o,slu-dig} - VSS_{e,slu-dig}) \cdot 10^{-3} \quad (S12)$$

$$M_{CO_2,eq,total} = M_{CO_2,biogas} \cdot FCF_{biogas} + M_{CH_4,biogas} \cdot 95\% \cdot FCF_{biogas} + GWP_{CH_4} \cdot M_{CH_4,biogas} \cdot 5\% \quad (S13)$$

In the formula:

$M_{CO_2,biogas}$ —direct CO₂ emissions from sludge anaerobic digestion, kgCO₂eq/d;

Q_{slu} —total sludge production, m³/d;

$VSS_{o,slu-dig}$ —VSS concentration of anaerobic digestion tank inlet sludge, mg/L;

$VSS_{e,slu-dig}$ —VSS concentration of anaerobic digestion tank outlet sludge, mg/L;

$HRT_{slu-dig}$ —anaerobic digestion tank hydraulic retention time, d;

$MLVSS_{slu-dig}$ —average concentration of mixed liquid volatile suspended solids, mg/L;

$M_{CH_4,biogas}$ —direct CH₄ emissions from sludge anaerobic digestion, kgCO₂eq/d;

Y_{dig} —anaerobic tank sludge yield coefficient, 0.08 kg MLVSS/kgBOD₅;

FCF_{biogas} —proportion of fossil carbon in biogas, 0.02

Tables

Table S1 Process operating parameters

Process	Facilities	Design parameter	Value	Unit
AO	Anaerobic Tank	Hydraulic Retention Time (HRT)	0.877	h
		F to M Ratio	0.832	kgBOD ₅ /(kgMLVSS·d)
	Aerobic Tank	Hydraulic Retention Time (HRT)	1.253	h
		Dissolved Oxygen Concentration	2.0	mg/L
		F to M Ratio	0.883	kgBOD ₅ /(kgMLVSS·d)
		Solid Retention Time (SRT)	8.483	d
	Secondary Clarifier	Surface Overflow Rate	12.99	m ³ /(m ² ·d)
		Maximum Settling Velocity	274	m/d
		Maximum Vesilind Settling Velocity	410	m/d
		Return Activated Sludge (RAS) Rate	7500	m ³ /d
Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	1.47	gAl/m ³	
AAO	Anaerobic Tank	Hydraulic Retention Time (HRT)	1.761	h
		F to M Ratio	0.895	kgBOD ₅ /(kgMLVSS·d)

		Hydraulic Retention Time (HRT)	1.188	h
	Anoxic Tank	Dissolved Oxygen Concentration	0.004	mg/L
		F to M Ratio	0.348	kgBOD ₅ /(kgMLVSS·d)
		Hydraulic Retention Time (HRT)	2.772	h
	Aerobic Tank	Dissolved Oxygen Concentration	2.0	mg/L
		F to M Ratio	0.182	kgBOD ₅ /(kgMLVSS·d)
		Return Activated Sludge (RAS) Rate	5000	m ³ /d
		Surface Overflow Rate	20.39	m ³ /(m ² ·d)
		Maximum Settling Velocity	274	m/d
	Secondary Clarifier	Maximum Vesilind Settling Velocity	410	m/d
		Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	0.91	gAl/m ³
		Hydraulic Retention Time (HRT)	2.314	h
	Anaerobic Tank	F to M Ratio	1.761	kgBOD ₅ /(kgMLVSS·d)
Bardenpho		Hydraulic Retention Time (HRT)	0.790	h
	Anoxic Tank1	Dissolved Oxygen Concentration	0.062	mg/L

	F to M Ratio	1.080	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	2.772	h
Aerobic Tank1	Dissolved Oxygen Concentration	5.9	mg/L
	F to M Ratio	0.542	kgBOD ₅ /(kgMLVSS·d)
	Return Activated Sludge (RAS) Rate	8000	m ³ /d
	Hydraulic Retention Time (HRT)	2.314	h
Anoxic Tank2	Dissolved Oxygen Concentration	0.0699	mg/L
	F to M Ratio	0.293	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	1.157	h
Aerobic Tank2	Dissolved Oxygen Concentration	2.9	mg/L
	F to M Ratio	0.409	kgBOD ₅ /(kgMLVSS·d)
	Surface Overflow Rate	7.994	m ³ /(m ² ·d)
	Maximum Settling Velocity	274	m/d
Secondary Clarifier	Maximum Vesilind Settling Velocity	410	m/d
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	1.56	gAl/m ³

StepAO

Anoxic Tank1	Hydraulic Retention Time (HRT)	1.984	h
	Dissolved Oxygen Concentration	0.003	mg/L
	F to M Ratio	0.654	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	1.488	h
	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.553	kgBOD ₅ /(kgMLVSS·d)
Aerobic Tank1	Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Hydraulic Retention Time (HRT)	1.722	h
	Dissolved Oxygen Concentration	0.008	mg/L
	F to M Ratio	0.754	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	1.292	h
	Dissolved Oxygen Concentration	2.0	mg/L
Anoxic Tank2	F to M Ratio	0.656	kgBOD ₅ /(kgMLVSS·d)
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Hydraulic Retention Time (HRT)	1.574	h
	Dissolved Oxygen Concentration	0.012	mg/L

	F to M Ratio	0.721	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	1.181	h
	Dissolved Oxygen Concentration	2.0	mg/L
Aerobic Tank3	F to M Ratio	0.658	kgBOD ₅ /(kgMLVSS·d)
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Surface Overflow Rate	7.994	m ³ /(m ² ·d)
	Maximum Settling Velocity	274.0	m/d
Secondary Clarifier	Maximum Vesilind Settling Velocity	410.0	m/d
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	1.43	gAl/m ³
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	Hydraulic Retention Time (HRT)	3.123	h
Anoxic Zone1	Dissolved Oxygen Concentration	0	mg/L
	F to M Ratio	0.654	kgBOD ₅ /(kgMLVSS·d)
StepCAS	Hydraulic Retention Time (HRT)	3.123	h
Aerobic Zone1	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.420	kgBOD ₅ /(kgMLVSS·d)

	Hydraulic Retention Time (HRT)	2.581	h
Anoxic Zone2	Dissolved Oxygen Concentration	0.005	mg/L
	F to M Ratio	0.661	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	2.581	h
Aerobic Zone2	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.403	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	2.314	h
Anoxic Zone3	Dissolved Oxygen Concentration	0.008	mg/L
	F to M Ratio	0.553	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	2.314	h
Aerobic Zone3	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.351	kgBOD ₅ /(kgMLVSS·d)
	Surface Overflow Rate	19.99	m ³ /(m ² ·d)
	Maximum Settling Velocity	274.0	m/d
Secondary Clarifier	Maximum Vesilind Settling Velocity	410.0	m/d
	Return Activated Sludge (RAS) Rate	2000	m ³ /d

	Chemical Dosage	PAC- $\text{Al}_2(\text{OH})_n\text{Cl}_{(6-n)}$ Dosage	3.14	gAl/m^3
	Anoxic Tank1	Hydraulic Retention Time (HRT)	2.189	h
		F to M Ratio	0.788	$\text{kgBOD}_5/(\text{kgMLVSS}\cdot\text{d})$
	Anaerobic Tank	Hydraulic Retention Time (HRT)	2.668	h
		F to M Ratio	1.203	$\text{kgBOD}_5/(\text{kgMLVSS}\cdot\text{d})$
	Anoxic Tank	Hydraulic Retention Time (HRT)	1.5	h
		Dissolved Oxygen Concentration	0.007	mg/L
		F to M Ratio	0.535	$\text{kgBOD}_5/(\text{kgMLVSS}\cdot\text{d})$
JHB	Aerobic Tank	Hydraulic Retention Time (HRT)	2.5	h
		Dissolved Oxygen Concentration	2.0	mg/L
		F to M Ratio	0.389	$\text{kgBOD}_5/(\text{kgMLVSS}\cdot\text{d})$
		Return Activated Sludge (RAS) Rate	6000	m^3/d
		Surface Overflow Rate	7.994	$\text{m}^3/(\text{m}^2\cdot\text{d})$
	Secondary Clarifier	Maximum Settling Velocity	274.0	m/d
		Maximum Vesilind Settling Velocity	410.0	m/d
		Return Activated Sludge (RAS) Rate	1500	m^3/d

Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	11.5	gAl/m ³
Anaerobic Tank	Hydraulic Retention Time (HRT)	1.16	h
	F to M Ratio	6.222	kgBOD ₅ /(kgMLVSS·d)
Anoxic Tank1	Hydraulic Retention Time (HRT)	1.868	h
	F to M Ratio	1.490	kgBOD ₅ /(kgMLVSS·d)
Anoxic Tank2	Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Hydraulic Retention Time (HRT)	2.802	h
	F to M Ratio	0.592	kgBOD ₅ /(kgMLVSS·d)
MUCT	Hydraulic Retention Time (HRT)	3.736	h
	Dissolved Oxygen Concentration	2.0	mg/L
Aerobic Tank	F to M Ratio	0.422	kgBOD ₅ /(kgMLVSS·d)
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
Secondary Clarifier	Solid Retention Time (SRT)	3.654	d
	Surface Overflow Rate	8.157	m ³ /(m ² ·d)
	Maximum Settling Velocity	274.0	m/d
	Maximum Vesilind Settling Velocity	410.0	m/d

		Return Activated Sludge (RAS) Rate	1500	m ³ /d
		Hydraulic Retention Time (HRT)	0.02613	h
		Ditch Velocity	0.01	m/s
	Oxidation Ditch	F to M Ratio	0.368	kgBOD ₅ /(kgMLVSS·d)
		Total Air Flow	759.6	m ³ /d
		Total Actual Oxygen Transfer Rate	23.07	kg/h
OD		Surface Overflow Rate	9.993	m ³ /(m ² ·d)
		Maximum Settling Velocity	274.0	m/d
	Secondary Clarifier	Maximum Vesilind Settling Velocity	410.0	m/d
		Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	1.43	gAl/m ³
		Hydraulic Retention Time (HRT)	1.702	h
	Anaerobic Tank	F to M Ratio	13.36	kgBOD ₅ /(kgMLVSS·d)
AO-BAF		Hydraulic Retention Time (HRT)	1.17	h
	Anoxic Tank	Dissolved Oxygen Concentration	0.04	mg/L
		F to M Ratio	7.974	kgBOD ₅ /(kgMLVSS·d)

		Hydraulic Retention Time (HRT)	2.73	h
	Aerobic Tank	Dissolved Oxygen Concentration	2.0	mg/L
		F to M Ratio	4.516	kgBOD ₅ /(kgMLVSS·d)
		Return Activated Sludge (RAS) Rate	5000	m ³ /d
		Dissolved Oxygen Concentration	2.0	mg/L
	Biological Aerated Filter	Hydraulic Loading Rate	141.03	m ³ /(m ² ·d)
		Organic Loading Rate	4.05	kgBOD ₅ /(m ³ ·d)
		BOD ₅ Removal Efficiency	94.96	%
		Media Specific Area	1000	m ² /m ³
		Surface Overflow Rate	20.39	m ³ /(m ² ·d)
	Secondary Clarifier	Maximum Settling Velocity	274.0	m/d
		Maximum Vesilind Settling Velocity	410.0	m/d
		Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	2.4	gAl/m ³
IFAS	MBBR/IFAS	Hydraulic Retention Time (HRT)	1.776	h
		Dissolved Oxygen Concentration	2.0	mg/L

		F to M Ratio	0.134	kgBOD ₅ /(kgMLVSS·d)
		Reactor Media Fill	50	%
		Media Specific Area	500	m ² /m ³
		Surface Overflow Rate	19.99	m ³ /(m ² ·d)
	Secondary Clarifier	Maximum Settling Velocity	274.0	m/d
		Maximum Vesilind Settling Velocity	410.0	m/d
		Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	2.12	gAl/m ³
	Anaerobic Tank	Hydraulic Retention Time (HRT)	0.594	h
		F to M Ratio	5.339	kgBOD ₅ /(kgMLVSS·d)
		Hydraulic Retention Time (HRT)	0.7942	h
	Anoxic Tank	Dissolved Oxygen Concentration	0.016	mg/L
AAO-MBR/VMBR		F to M Ratio	1.150	kgBOD ₅ /(kgMLVSS·d)
		Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Aerobic Tank	Hydraulic Retention Time (HRT)	4.15	h
		Dissolved Oxygen Concentration	2.0	mg/L

	F to M Ratio	0.202	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	0.5935	h
	Dissolved Oxygen Concentration	8.0	mg/L
MBR	F to M Ratio	0.315	kgBOD ₅ /(kgMLVSS·d)
	Cross-flow Air Flow	19000	m ³ /d
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Anaerobic Tank	Hydraulic Retention Time (HRT)	1.163	h
	F to M Ratio	2.834	kgBOD ₅ /(kgMLVSS·d)
	Hydraulic Retention Time (HRT)	1.319	h
Anoxic Tank	Dissolved Oxygen Concentration	0.006	mg/L
	F to M Ratio	1.245	kgBOD ₅ /(kgMLVSS·d)
Anammox	Return Activated Sludge (RAS) Rate	2000	m ³ /d
	Hydraulic Retention Time (HRT)	3.077	h
Aerobic Tank	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.495	kgBOD ₅ /(kgMLVSS·d)
Completely-Mixed Tank	Hydraulic Retention Time (HRT)	3.878	h

	Dissolved Oxygen Concentration	2.0	mg/L
	F to M Ratio	0.272	kgBOD ₅ /(kgMLVSS·d)
Anammox CSTR Tank	Hydraulic Retention Time (HRT)	3.877	h
	F to M Ratio	0.016	kgBOD ₅ /(kgMLVSS·d)
Hydrocyclone Solid Separation	Solid Capture Rate	80	%
	Constant Flow	1	m ³ /d
	Surface Overflow Rate	20.39	m ³ /(m ² ·d)
Secondary Clarifier	Maximum Settling Velocity	274.0	m/d
	Maximum Vesilind Settling Velocity	410.0	m/d
	Return Activated Sludge (RAS) Rate	2000	m ³ /d
Chemical Dosage	PAC-Al ₂ (OH) _n Cl _(6-n) Dosage	0.89	gAl/m ³

Table S2 Chemometric parameters

Name of Chemometric Parameter	Unit	Parameters
Fermentation biological yield	gCOD/gCOD	0.18
Ammonia-oxidizing bacteria yield	gCOD/gN	0.18
Yield of nitrifying bacteria	gCOD/gN	0.06
Aerobic yield of phosphorus accumulating bacteria	gCOD/gCOD	0.64
Based on the yield of hydrogen methanogens	gCOD/gCOD	0.06

The parameters in the table are the system's default values.

Table S3 Kinetic parameters

Type of Bacteria	Kinetics Name	Unit	Parameters
Heterotrophic bacteria	Maximum specific growth rate	1/d	3.2
	Oxygen saturation factor	mgO ₂ /L	0.20
	Ammonia saturation factor	mgN/L	0.05
	P saturation factor	mgP/L	0.01
	Aerobic decay rate	1/d	0.62
Methanolic nutrient bacteria	Maximum growth rate	1/d	1.30
	Oxygen saturation factor	mgO ₂ /L	0.20
	Methanol saturation factor	mgCOD/L	0.50
	Nitrite saturation factor	mgN/L	0.10
	Nitrate saturation factor	mgN/L	0.10
Ammonia Oxidizing Bacteria	Aerobic decay rate	1/d	0.20
	Maximum growth rate	1/d	0.90
	Oxygen saturation factor	mgO ₂ /L	0.25
Nitrifying bacteria	Ammonia saturation factor	mgN/L	0.70
	Aerobic decay rate	1/d	0.17
	Maximum growth rate	1/d	1.00
	Oxygen saturation factor	mgO ₂ /L	0.65

	Nitrite saturation factor	mgN/L	0.50
	Decay rate	1/d	0.17
	Maximum growth rate	1/d	0.019
Anammox bacteria	Oxygen saturation factor	mgO ₂ /L	0.10
	Nitrite saturation factor	mgN/L	0.73
	Aerobic decay rate	1/d	0.0058
	Maximum growth rate	1/d	1.00
	Oxygen saturation factor	mgO ₂ /L	0.20
	Sac saturation factor	mgCOD/L	4.00
	Spro saturation factor	mgCOD/L	4.00
Polyphosphate Bacteria	Xpp/Xbp saturation factor	gp/gCOD	0.01
	PHA saturation factor	gCOD/gPAO/d	0.01
	Nitrite saturation factor	mgN/L	0.50
	Nitrate saturation factor	mgN/L	0.50
	Maximum fermentation rate	1/d	3.00
	Oxygen saturation factor	mgO ₂ /L	0.10
Fermenting Bacteria	Substrate saturation factor	mgCOD/L	4.00
	Nitrate-Nitrogen saturation factor	mgN/L	0.10
	Aerobic decay coefficient	1/d	0.13
	Maximum growth rate	1/d	0.35
Acetic acid-producing bacteria	Undissociated propionic acid saturation factor	mgCOD/L	10.00
	Aerobic decay factor	1/d	0.067
	Maximum growth rate	1/d	0.37
Hydrogen and Methane Producing Bacteria	Hydrogen saturation factor	mgCOD/L	2.50
	Aerobic decay coefficient	1/d	0.033

Note: The parameters in the table are the system's default values.

Table S4 Kinetic parameters for Anammox process

Type of Bacteria	Kinetics Name	Unit	Default Parameters	Modified Parameters
Anammox bacteria	Maximum growth rate	1/d	0.01855	0.02
	Anoxic reduction factor for decay rate	mgO ₂ /L	0.5	0.70
	Anaerobic reduction factor for decay rate	mgO ₂ /L	0.3	0.40
	Aerobic decay rate	1/d	0.0058	0.06

Table S5 Process influent and effluent water standards

Water quality indicators	H-A		M-A		L-A		H-IV		M-IV		L-IV	
	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff
COD	1000	50	500	50	250	50	1000	30	500	30	250	30
BOD ₅	400	10	220	10	110	10	400	10	220	10	110	10
SS	350	10	200	10	100	10	350	10	200	10	100	10
TN	85	15	40	15	20	15	85	10	40	10	20	10
NH ₃ -N	64	5	30	5	15	5	64	1.5	30	1.5	15	1.5
TP	15	0.5	8	0.5	4	0.5	15	0.3	8	0.3	4	0.3

Note: "Inf" represents the Influent quality (mg/L) and "Eff" represents the Effluent standard (mg/L).

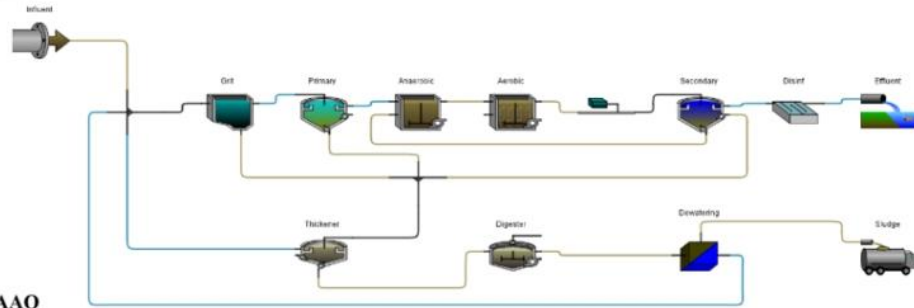
Table S6 Pareto sorting results of wastewater treatment processes

Pareto level	Processes	scenario	Pareto level	Processes	scenario	Pareto level	Processes	scenario	Pareto level	Processes	scenario
1	Step AO	M-A	2	AAO+MBR	L-A	3	IFAS	L-A	5	Anammox	H-IV
1	MUCT	M-A	2	AAO+MBR	M-IV	3	IFAS	L-IV	5	AO	L-A
1	AAO+MBR	M-A	3	AO	H-A	3	IFAS	H-A	5	AO	H-IV
1	AAO+MBR	L-IV	3	OD	M-IV	4	Anammox	M-A	5	Anammox	M-IV
1	AO-BAF	H-A	3	Bardenpho	L-IV	4	SBR	L-A	5	AO	L-IV
1	AO-BAF	M-A	3	AAO	M-A	4	AO	H-A	5	JHB	L-A
1	AO-BAF	H-IV	3	Step AO	H-IV	4	Anammox	H-A	6	AO	M-4
1	AO-BAF	M-IV	3	MUCT	L-A	4	MABR	L-IV	6	Step CAS	L-A
1	AO-BAF	M-IV	3	AAO	H-A	4	JHB	H-IV	6	SBR	M-A
1	AAO+VMBR	H-A	3	Step AO	H-A	4	MUCT	H-IV	6	AO	M-IV
1	AAO+VMBR	M-A	3	MUCT	H-A	4	OD	H-A	7	AnMBR	H-IV
1	AAO+VMBR	L-A	3	AAO	L-A	4	Step CAS	H-A	7	SBR	M-IV
1	AAO+VMBR	M-IV	3	Step AO	L-IV	4	IFAS	H-A	8	MABR	M-A

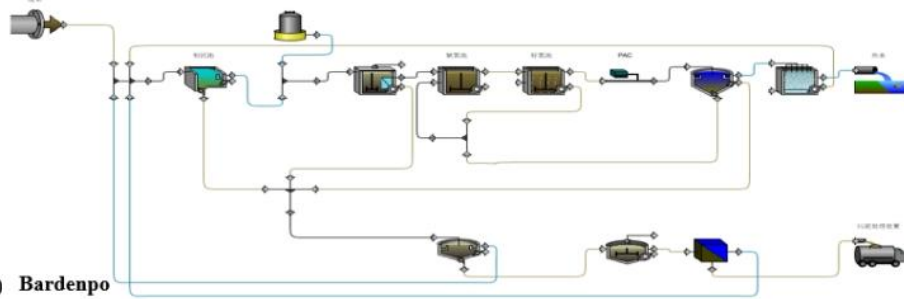
1	AAO+VMBR	L-IV	3	SBR	H-IV	4	OD	L-IV
2	IFAS	M-IV	3	AAO+VMBR	H-IV	4	Bardenpho	L-A
2	AO-BAF	L-A	3	AO	M-A	4	Step CAS	M-IV
2	AAO+MBR	H-A	3	JHB	M-A	4	Step CAS	H-IV
2	Step AO	L-A	3	JHB	M-IV	4	Step CAS	M-A
2	Bardenpho	H-A	3	AAO	H-IV	4	Bardenpho	M-A
2	Step AO	M-IV	3	AAO	L-IV	4	MUCT	L-IV
2	MUCT	M-IV	3	IFAS	L-IV	5	SBR	H-A
2	Step-AO	H-A	3	Anammox	L-A	5	MABR	M-A
2	AAO	H-A	3	Anammox	L-IV	5	Step CAS	L-IV
2	AAO	M-IV	3	AAO+MBR	H-IV	5	JHB	L-IV
2	Bardenpho	H-IV	3	OD	M-A	5	OD	L-A
2	Bardenpho	M-IV	3	OD	H-IV	5	SBR	L-IV

Figures

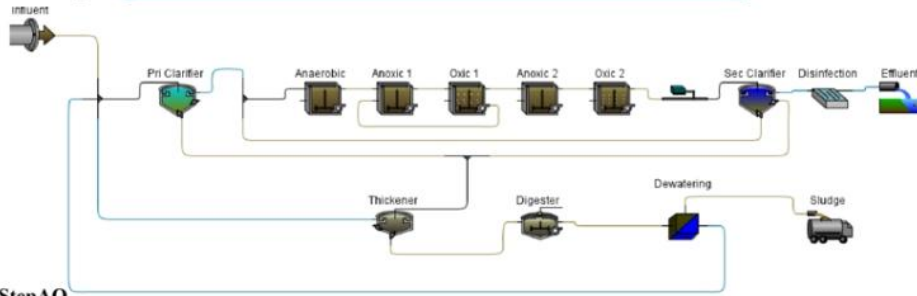
(1) AO



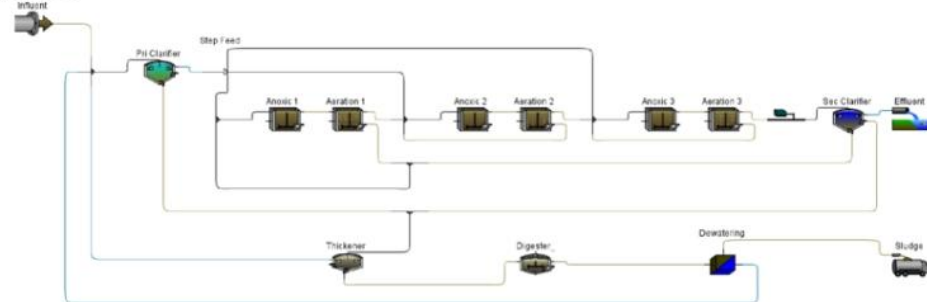
(2) AAO



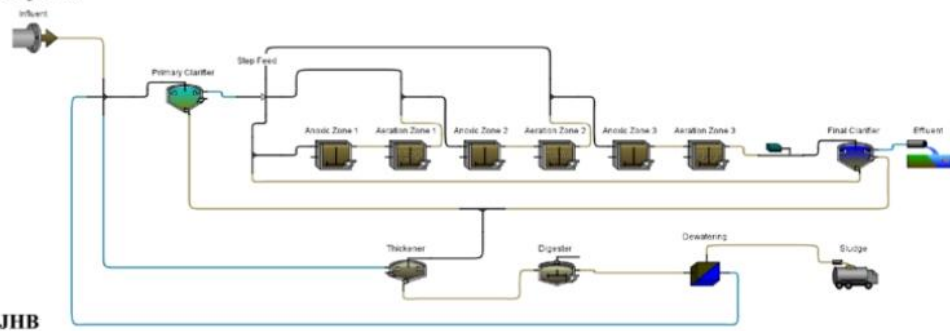
(3) Bardenpho



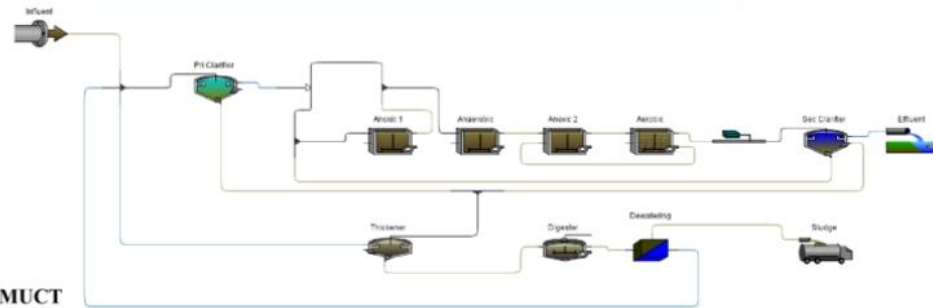
(4) StepAO



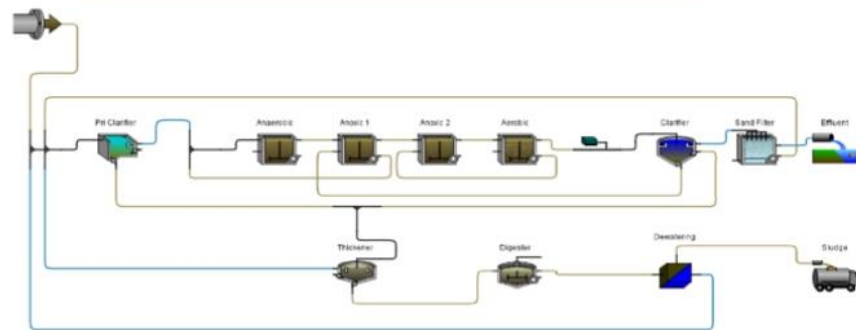
(5) StepCAS



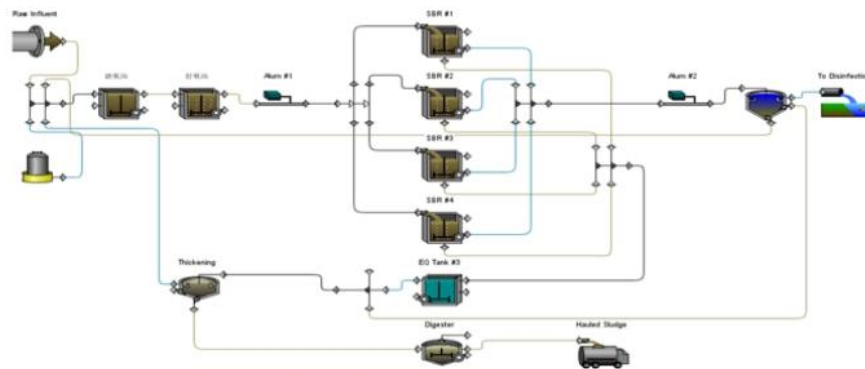
(6) JHB



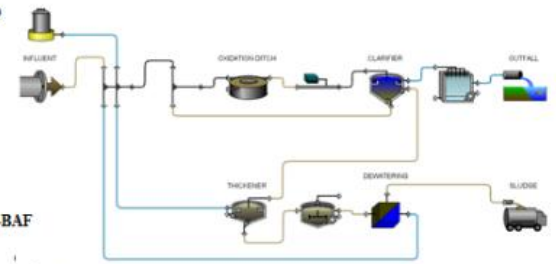
(7) MUCT



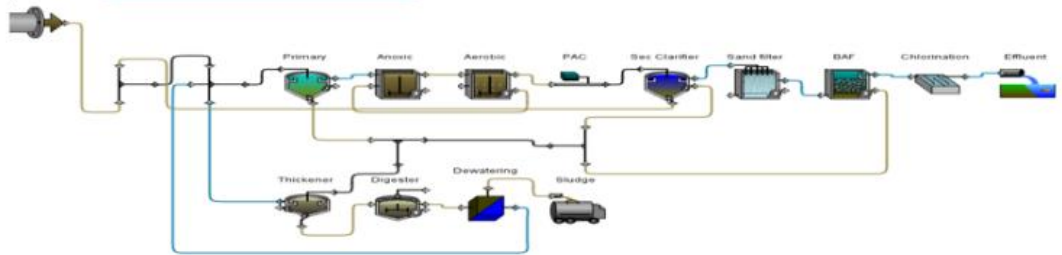
(8) SBR



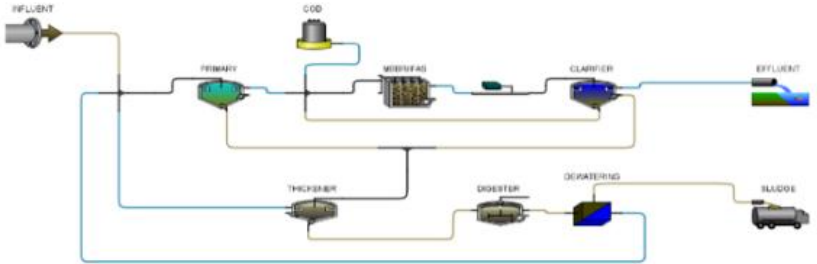
(9) OD



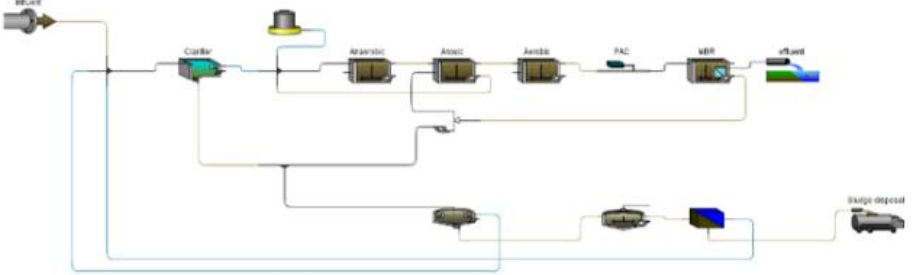
(10) AO-BAF



(11) IFAS



(12) AAO-MBR/VMBR



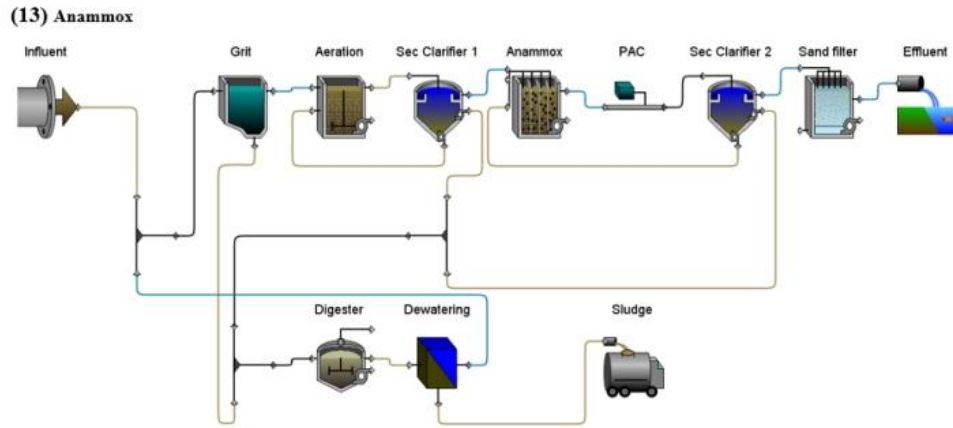


Fig. S1 Model generalization diagrams of wastewater treatment process

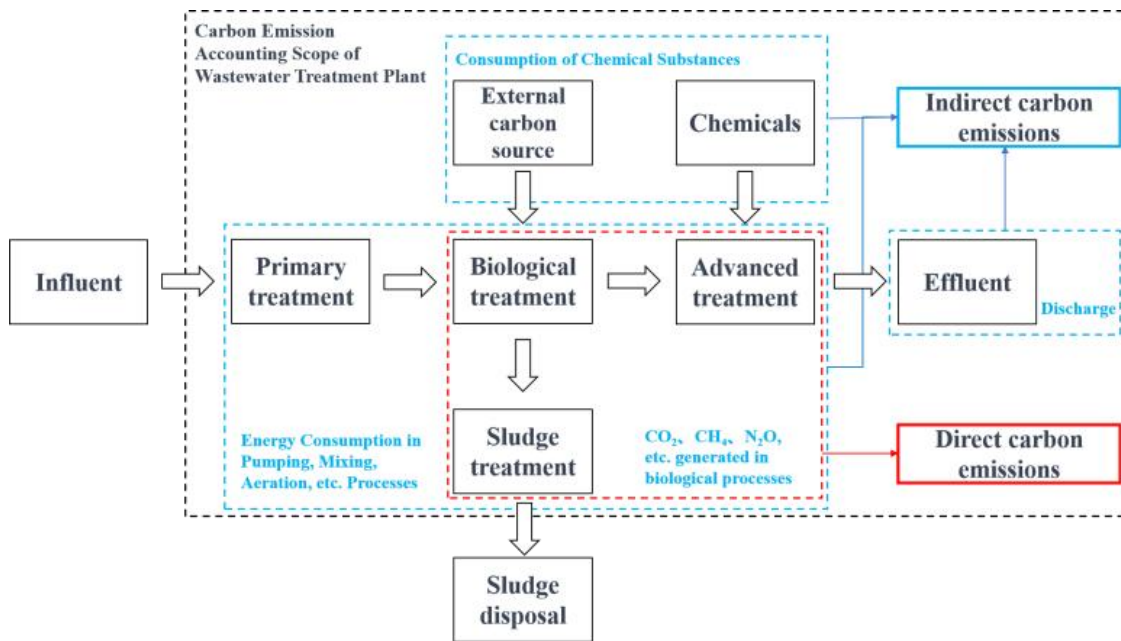


Fig. S2 Schematic Scope of Carbon Accounting