Supplementary Materials: Application of Emergy Analysis to the Sustainability Evaluation of Municipal Wastewater Treatment Plants

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Table S1. Emergy inventory for Case 1.

Item	Basic Data (Unit/Year)	Transformity (sej/Unit)	Emergy (sej/Year)	Unit ton of Emergy (sej/Ton/Year)
Input				
1 W_{in}	1.08×10^{14} J	6.12×10^{6}	6.63×10^{20}	6.14×10^{13}
R				
2 Solar Energy	5.21×10^{13} J	1.00	5.21×10^{13}	4.82×10^{6}
3 Air	1.21×10^{11} g	5.16×10^{7}	6.23×10^{18}	5.77×10^{11}
4 Wind	7.24×10^{11} J	1.50×10^{3}	1.09×10^{15}	1.01×10^{8}
5 Rain	2.51×10^{11} J	2.93×10^{4}	7.35×10^{15}	6.80×10^{8}
6 Earth Rotation	2.40×10^{11} J	5.57×10^{4}	1.34×10^{16}	1.24×10^{9}
Total of R			6.25×10^{18}	5.79×10^{11}
N				
7 Soil Organics	5.28×10^{13} J	7.11×10^{4}	3.75×10^{18}	3.48×10^{11}
F_R				
8 Water	3.00×10^{9} g	1.07×10^{6}	3.21×10^{15}	2.97×10^{8}
9 Manpower	3.19×10^{10} J	1.24×10^{7}	3.95×10^{17}	3.66×10^{10}
Total of F_R			3.98×10^{17}	3.69×10^{10}
F_N				
10 Electricity	1.73×10^{13} J	1.19×10^{5}	2.06×10^{18}	1.91×10^{11}
F_S				
11 Investment	8.04×10^{5} $	5.57×10^{12}	4.48×10^{18}	4.14×10^{11}
12 Cost	2.02×10^{6} $	5.57×10^{12}	1.13×10^{19}	1.04×10^{12}
Total of F_S			1.58×10^{19}	1.46×10^{12}
Total Input			6.91×10^{20}	6.40×10^{13}
Output				
13 Sludge	5.14×10^{9} g	7.60×10^{9}	3.91×10^{19}	3.62×10^{12}
14 ECEW			1.25×10^{20}	1.15×10^{13}
Total Output			1.64×10^{20}	1.52×10^{13}
P	2.08×10^{5} $	5.57×10^{12}	1.16×10^{18}	1.07×10^{11}

Table S2. Emergy inventory for Case 2.

Item	Basic Data (Unit/Year)	Transformity (sej/Unit)	Emergy (sej/Year)	Unit ton of Emergy (sej/Ton/Year)
Input				
1 W_{in}	1.15×10^{14} J	6.12×10^{6}	7.01×10^{20}	6.49×10^{13}
R				
2 Solar Energy	3.80×10^{13} J	1.00	3.80×10^{13}	3.52×10^{6}
3 Air	1.09×10^{11} g	5.16×10^{7}	5.63×10^{18}	5.21×10^{11}
4 Wind	5.28×10^{11} J	1.50×10^{3}	7.92×10^{14}	7.33×10^{7}
5 Rain	1.83×10^{11} J	2.93×10^{4}	5.36×10^{15}	4.96×10^{8}
6 Earth Rotation	1.75×10^{11} J	5.57×10^{4}	9.75×10^{15}	9.03×10^{8}

Table S2. *Cont.*

Item	Basic Data (Unit/Year)	Transformity (sej/Unit)	Emergy (sej/Year)	Unit ton of Emergy (sej/Ton/Year)
Total of R			5.64×10^{18}	5.23×10^{11}
N				
7 Soil Organics	3.85×10^{13} J	7.11×10^{4}	2.74×10^{18}	2.53×10^{11}
F_R				
8 Water	7.30×10^{9} g	1.07×10^{6}	7.81×10^{15}	7.23×10^{8}
9 Manpower	1.82×10^{10} J	1.24×10^{7}	2.26×10^{17}	2.09×10^{10}
Total of F_R			2.34×10^{17}	2.16×10^{10}
F_N				
10 $FeSO_4$	7.20×10^{7} g	2.65×10^{9}	1.91×10^{17}	1.77×10^{10}
11 Electricity	7.88×10^{12} J	1.19×10^{5}	9.38×10^{17}	8.68×10^{10}
Total of F_N			1.13×10^{18}	1.04×10^{11}
F_S				
12 Investment	2.99×10^{5} $	5.57×10^{12}	1.67×10^{18}	1.54×10^{11}
13 Cost	7.90×10^{5} $	5.57×10^{12}	4.40×10^{18}	4.08×10^{11}
Total of F_S			6.07×10^{18}	5.62×10^{11}
Total Input			7.17×10^{20}	6.64×10^{13}
Output				
14 Sludge	3.43×10^{9} g	$7.60\ 43 \times 10^{9}$	2.61×10^{19}	2.41×10^{12}
15 ECEW			1.25×10^{20}	1.15×10^{13}
Total Output			1.51×10^{20}	1.39×10^{13}
P	1.39×10^{5} $	5.57×10^{12}	7.76×10^{17}	7.18×10^{10}

Table S3. Emergy inventory for Case 3.

Item	Basic Data (Unit/Year)	Transformity (sej/Unit)	Emergy (sej/Year)	Unit ton of emergy (sej/Ton/Year)
Input				
1 W_{in}	2.85×10^{14} J	6.12×10^{6}	1.74×10^{21}	6.05×10^{13}
R				
2 Solar Energy	2.71×10^{13} J	1.00	2.71×10^{13}	9.42×10^{5}
3 Air	1.10×10^{11} g	5.16×10^{7}	5.69×10^{18}	1.98×10^{11}
4 Wind	3.77×10^{11} J	1.50×10^{3}	5.66×10^{14}	1.96×10^{7}
5 Rain	1.31×10^{11} J	2.93×10^{4}	3.83×10^{15}	1.33×10^{8}
6 Earth Rotation	1.25×10^{11} J	5.57×10^{4}	6.96×10^{15}	2.42×10^{8}
Total of R			5.70×10^{18}	1.98×10^{11}
N				
7 Soil Organics	2.75×10^{13} J	7.11×10^{4}	1.96×10^{18}	6.79×10^{10}
F_R				
8 Water	1.83×10^{10} g	1.07×10^{6}	1.95×10^{16}	6.78×10^{8}
9 Manpower	2.73×10^{10} J	1.24×10^{7}	3.39×10^{17}	1.18×10^{10}
Total of F_R			3.58×10^{17}	1.24×10^{10}
F_N				
10 PAM	1.04×10^{7} g	2.65×10^{9}	2.76×10^{16}	9.57×10^{8}
11 Electricity	1.49×10^{13} J	1.19×10^{5}	1.77×10^{18}	6.16×10^{10}
Total of F_N			1.80×10^{18}	6.25×10^{10}
F_S				
12 Investment	5.79×10^{5} $	5.57×10^{12}	3.23×10^{18}	1.12×10^{11}
13 Cost	1.62×10^{6} $	5.57×10^{12}	9.01×10^{18}	3.13×10^{11}
Total of F_S			1.22×10^{19}	4.25×10^{11}
Total Input			1.77×10^{21}	6.13×10^{13}
Output				
14 Sludge	7.66×10^{9} g	7.60×10^{9}	5.82×10^{19}	2.02×10^{12}
15 ECEW			6.28×10^{20}	2.18×10^{13}
Total Output			6.87×10^{20}	2.38×10^{13}
P	3.11×10^{5} $	5.57×10^{12}	1.73×10^{18}	6.01×10^{10}

Table S4. Emergy inventory for Case 4.

Item	Basic Data (Unit/Year)	Transformity (sej/Unit)	Emergy (sej/Year)	Unit ton of Emergy (sej/Ton·Year)
Input				
1 W_{in}	4.58×10^{14} J	6.12×10^{6}	2.80×10^{21}	6.49×10^{13}
R				
2 Solar Energy	3.80×10^{13} J	1.00	3.80×10^{13}	8.79×10^{5}
3 Air	2.37×10^{11} g	5.16×10^{7}	1.22×10^{19}	2.83×10^{11}
4 Wind	5.28×10^{11} J	1.50×10^{3}	7.92×10^{14}	1.83×10^{7}
5 Rain	1.83×10^{11} J	2.93×10^{4}	5.36×10^{15}	1.24×10^{8}
6 Earth Rotation	1.75×10^{11} J	5.57×10^{4}	9.75×10^{15}	2.26×10^{8}
Total of R			1.22×10^{19}	2.83×10^{11}
N				
7 Soil Organics	3.85×10^{13} J	7.11×10^{4}	2.74×10^{18}	6.34×10^{10}
F_R				
8 Water	1.20×10^{10} g	1.07×10^{6}	1.28×10^{16}	2.97×10^{8}
9 Manpower	4.01×10^{10} J	1.24×10^{7}	4.97×10^{17}	1.15×10^{10}
Total of F_R			5.10×10^{17}	1.18×10^{10}
F_N				
10 $FeCl_3$	3.285×10^{8} g	2.65×10^{9}	8.71×10^{17}	2.02×10^{10}
11 PAM	6.53×10^{7} g	2.65×10^{9}	1.73×10^{17}	4.01×10^{9}
12 Electricity	3.55×10^{13} J	1.19×10^{5}	4.22×10^{18}	9.78×10^{10}
Total of F_N			5.27×10^{18}	1.22×10^{11}
F_S				
13 Investment	7.24×10^{5} $	5.57×10^{12}	4.03×10^{18}	9.33×10^{10}
14 Cost	1.98×10^{6} $	5.57×10^{12}	1.10×10^{19}	2.55×10^{11}
Total of F_S			1.50×10^{19}	3.48×10^{11}
Total Input			2.84×10^{21}	6.57×10^{13}
Output				
15 Sludge	2.10×10^{10} g	7.60×10^{9}	1.60×10^{20}	3.69×10^{12}
16 ECEW			4.98×10^{20}	1.15×10^{13}
Total Output			6.58×10^{20}	1.52×10^{13}
P	8.53×10^{5} $	5.57×10^{12}	4.75×10^{18}	1.10×10^{11}

Note: As the wind energy, rain potential energy and solar energy belong to the same source, we selected the maximal emergy value of the three items in the process of calculating the sum of renewable natural resources emergy *R* in order to avoid repeated calculation [51]. The models used to calculate the Basic data are as follows: **Wastewater** [51] = Wastewater treatment capacity (m^3/d) × Water density (1.00×10^6 g/m^3) × 360 d/yr × Gibbs free energy (4.91 J/g) + Concentration of COD (g/L) × 3.4 kcal/g × 4186 J/kcal × Wastewater treatment capacity (m^3/d) × 360 d/yr × 1000 L/m^3. **Solar Energy** [49] = Occupied area (m^2) × Average solar radiation (J/m^2·yr) × Solar absorption coefficient (0.7). **Air** [49] = Volume (m^3·yr) × Air density (1.23×10^3g/m^3). **Wind** [49] = Occupied area (m^2) × Air density (1.23×10^3 g/m^3) × Drag coefficient (0.001) × (Average annual wind velocity (m/s) × (10/6))^3 × (360 × 24 × 3600 s/yr). **Rain** [49] = Occupied area (m^2) × Yearly precipitation (m/yr) × Evaporation × Water density (1000 kg/m^3) × Gibbs free energy (4910 J/kg). **Earth Rotation** [49] = Occupied area (m^2) × Heat flux (J/m^2·yr). **Manpower** [50] = 1740 h/yr × Number of employees × 125 kcal/h × 4186 J/kcal. **Electricity** = Annual electricity consumption (kWh/yr) × 3.60×10^6 J/kWh).)

Table S5. List of symbols and implications.

Symbol	Implication
EYR	Emergy Yield Ratio
ELR	Environment Load Ratio
ESI	Emergy Sustainable Indices
IEYR	Improved Emergy Yield Ratio
IELR	Improved Environment Load Ratio
IESI	Improved Emergy Sustainable Index
N	Non-renewable Natural Resources Emergy
R	Renewable Natural Resources Emergy
F	Purchased Emergy
W_{in}	Wastewater Input Emergy
F_R	Purchased Renewable Resources Emergy
F_N	Purchased Non-renewable Resources Emergy
F_S	Capital Emergy
W_{out}	Drainage Emergy
ECEC	Emergy Consumption of diluting the Emission of Water pollutant
S	Sludge Emergy
P	Capital Emergy for Sludge Disposal