environments

Supplementary Material

This supplement accompanies the revised prospective comparison of SS and OF-MSW treatment with PHA recovery and candidate fertilizer coating. It defines the final product, identifies reference assumptions and supplies updated comparison conventions. The tables summarize the reference case and selected sensitivity scenarios described in the manuscript.

Mass and energy for the candidate coated product

Final coated mass consists of 98% predried compost core and 2% PHA. The core is specified at 90% TS; water removed from the allocated wet compost receives a separate thermal duty. Final coated output is limited by both available polymer and the 68% compost allocation. Unallocated wet compost and surplus PHA remain physical outputs. Polymer capture precedes extraction, and unrecovered polymer remains in the named residual stream returned to digestion.

A 5 wt% polymer solution requires 19 kg solvent per kilogram of coating polymer, or 0.38 kg/kg final product. Concentrations of 2 wt% and 10 wt% are evaluated as sensitivity cases. The original 0.02 kg/kg final solvent dose implies a 50 wt% polymer solution and is excluded from the reference case because this concentration is unsupported. Reference solvent capture is 99%, with 0.5 kWh/kg captured solvent added for recovery; the solvent supply burden is retained without an avoided-product credit. Fugitive solvent mass is explicit, but complete direct-emission toxicity characterization is unavailable.

Source equipment duties are 0.083 kWh/kg pelletization, 0.055 pan motor, 0.15 fans, 0.6 heater and 0.0039 compressed air, totaling 0.8919 kWh/kg final product [47–51]. The coating-heater duty is not duplicated in the external heat demand. Core predrying and PHA recovery drying are distinct services, using 1.2 kWh/kg evaporated water. These are prospective duties; equipment suitability, actual solvent concentration and release performance are not validated.

Table S1. Historical European electricity-generation shares for the 2050 scenario [52], retained for context only. The “Other sources” category replaces the former “Geothermal” label. No future-grid LCIA is executed from these shares alone.

Source	Share (%)
Coal	5.90
Lignite	0.05
Oil	0.20
Gas	41.50
Nuclear	24.40
Biomass	3.30
Hydro	15.10
Wind	7.00
Other sources	2.55
Total	100.00

Table S2. Revised percentage change, 100 × (integration − baseline) / |baseline|. Positive values indicate higher characterized impacts. Values concern the current characterization scope; near-zero ODP baselines are reported through absolute results in main Table 5 instead of unstable percentages.

Category	SS change (%)	OFMSW change (%)
AD-elements	4.90×10^2	9.58×10^2
AD-fossil	4.07×10^2	4.36×10^2
GWP	6.67×10^2	5.48×10^2
ODP	See main Table 5	See main Table 5
HTP	2.27×10^3	1.19×10^3
FAETP	3.67×10^2	3.65×10^2
MAETP	2.93×10^2	3.13×10^2
TETP	2.20×10^3	1.17×10^3
PCOP	2.55×10^3	3.28×10^3
AP	1.88×10^2	2.86×10^2
EP	1.77×10^1	3.12×10^1

Table S3. Principal reference assumptions. These are model inputs, not new measurements.

Driver	Reference value and unit	Evidence status
Incoming raw OFMSW TS	0.39700 kg TS/kg wet	Original manuscript raw-waste assumption [52]; Inherited composition assumption; not new plant measurement
Reject TS fraction	0.39700 kg TS/kg wet	Equal to incoming raw TS in reference; varied independently; Design assumption; sensitivity range documented
OFMSW concentration after dilution	0.12000 kg TS/kg wet	120 g TS/kg pretreated wet material; [42,53]; Source concentration; process water explicit
SS COD per VS	1.42000 kg COD/kg VS	Source biomass conversion; CHO surrogate [49,51]; Design assumption; sensitivity range documented
VFA COD per dry mass	1.50000 kg COD/kg VFA	Lumped acid mixture assumption; [42,53] composition context; Design assumption; sensitivity range documented
Particle and polymer capture	0.74000 fraction	Source solid separation assumption [45]; Uniform particle capture; including PHA
Extraction recovery after capture	0.90000 fraction	Prospective recovery below source 100% [50]; Design assumption; sensitivity range documented
SS accumulation COD yield	0.28484 kg PHA COD/kg VFA COD	Source 32% PHA of final cell dry mass, selection yield and monomer factors; Source content definition reconciled; final cells include stored polymer
OFMSW accumulation COD yield	0.44000 kg PHA COD/kg VFA COD	Source yield [16]; inherited reference assumption
CHP electrical efficiency	0.40000 kWh/kWh fuel	[42,53], CHP balance; original 55% replaced; Literature assumption
CHP recoverable heat efficiency	0.50000 kWh/kWh fuel	[42,53], CHP balance; original 45% replaced; Literature assumption; total 90%
Methane leakage	0.01000 kg/kg produced	Prospective allowance; 1% and 3% tested; Design assumption; sensitivity range documented

Driver	Reference value and unit	Evidence status
Continuous mixing power density	0.00660 kW/m3	Mechanical mixing engineering allowance; [51] context; Design coefficient; 0.5-2 times tested
Equivalent hydraulic pumping head	10.00000 m	Assumed total head per transfer; Design assumption; sensitivity range documented
Pump efficiency	0.65000 fraction	Assumed hydraulic efficiency; Design assumption; sensitivity range documented
Sensible heat recuperation	0.50000 fraction	Design assumption; zero and 50% tested; Design assumption; sensitivity range documented
Annual reactor heat loss allowance	0.50000 kWh/m3 reactor/d	Prospective thermal design; Fixed reference allowance; actual tank geometry unavailable
Composting biogenic organic conversion	0.35000 fraction	Prospective stabilization assumption; 0.2-0.5 tested; Design assumption; sensitivity range documented
Yard waste TS	0.50000 kg/kg wet	Prospective bulking composition; Design assumption; sensitivity range documented
Yard waste VS/TS	0.90000 kg/kg TS	Prospective bulking composition; Design assumption; sensitivity range documented
Compost ammonia emission	0.50000 kg/t wet cake	Prospective emission allowance; not a regulatory limit; Fixed reference assumption; unmeasured category-specific uncertainty
Dried pellet core TS	0.90000 kg TS/kg core	Prospective pellet moisture specification; Core pre-drying included as distinct thermal service
PHA concentration in coating solution	0.05000 kg PHA/kg solution	Prospective 5 wt% solution; source 50 wt% implied dose replaced; 2-10 wt% tested; dissolution and equipment suitability not validated
Residual wastewater treatment multiplier	1.00000 factor	Wastewater-treatment exchange vector from source inventory, scaled to residual COD; Proxy; 1 and 2 times tested; sludge disposal and salinity uncertainty remain

Table S4. Revised annual energy balance, kWh/y. Internal useful heat is accounted for once; external heat export is zero in the reference. Equipment and residual-treatment duties are prospective assumptions.

Configuration	Electricity demand	CHP electricity	Net import (+) / export (-)	Useful heat demand	External heat
SS-B	335,854	873,575	-537,721	872,401	0
SS-PHA	981,343	833,505	147,838	2,065,913	1,024,032
OFMSW-B	14,879,923	42,934,318	-28,054,395	36,450,446	0
OFMSW-PHA	55,263,952	39,498,820	15,765,132	117,428,054	68,054,528

Table S5. Coating and downstream assumptions used consistently in the revised reference. Source equipment duties are retained where applicable; new concentration and moisture assumptions are explicit.

Quantity	Reference value	Qualification
Final coating fraction	2 wt%	PHA/final product; actual core = 98%

Quantity	Reference value	Qualification
Predried core solids	90 wt%	Wet core predrying charged separately
PHA recovery	74% capture × 90% extraction	Uniform capture; actual residues returned to AD
Coating solution	5 wt% PHA	19 kg solvent/kg coating polymer
Coating electricity	0.8919 kWh/kg final	Includes heater; no duplicate external duty
Solvent capture	99%	0.5 kWh/kg captured; no recovery credit
PHA drying	1 kg water/kg dry PHA	1.2 kWh/kg water
Core drying	Actual water removal	1.2 kWh/kg water; distinct upstream service

Table S6. Executed sensitivity ranges. These are scenario bounds, not measured confidence intervals or an exhaustive uncertainty distribution.

Driver	Executed range	Dependent quantities
PHA formation	0.75–1.25 × reference	Respiration, recovery, AD load, gas and compost
Capture and extraction	60–90%; 70–100%	Physical polymer and residual routing
Aeration / equipment	0.5–2 × reference	Annual electricity and net energy
AD conversion	SS 45–65%; OFMSW 55–75%	VS, COD, gas and digestate
Compost conversion	20–50%	Compost mass, evaporation and heat
CHP and heat recuperation	40/50% vs 38/38%; recuperation 0–50%	Generation and useful annual heat
Coating solution	2–10 wt% PHA	Solvent mass and recovery electricity
Substitution	Reference zero; explicit upper cases	Eligible equivalent-product flows only
Pretreatment	Reject TS 20–80%	Accepted solids and dilution
Residual treatment	1–2 × reference proxy	Downstream characterized exchanges

Table S7. Entry flow and functional-unit conventions. Comparisons remain within each feedstock pair.

Configuration	Annual incoming wet flow	Primary reference flow
SS pair	4,050.45648 t/y	Dewatered sludge at subsystem entry
OFMSW pair	145,000 t/y	Raw incoming wet OFMSW
SS common upstream	5,625,634 m³ wastewater/y	Excluded from sludge comparison
Internal liquid returns	Explicit calculated wet mass	Not extra incoming functional units

Table S8. Background characterization provenance and availability. Scalar vectors permit numerical replication; dataset-level reconstruction remains limited.

Item	Documentation supplied	Remaining limitation
Exchange coefficients	34 × 11 scalar characterization values	Original background process inventories unavailable
Reference method	Inherited CML-labeled vectors [59]	Exact implementation metadata not fully documented
Electricity	Same vector for imports/exports	No validated future-grid vector

Item	Documentation supplied	Remaining limitation
Database mapping	Source inventory and documented update history	Dataset UUID, geography and system model unavailable
Normalization	Not used to aggregate categories	No unsupported population-equivalent interpretation
Residual treatment	Wastewater-treatment proxy from source inventory; sensitivity assessed	Not a validated treatment design for these liquors

Table S9. Principal changes to the original inventory and their revised implementation.

Source issue	Revised implementation
Independent TS and VS destruction	Conserved FS; derived digestate TS and wet mass
Raw/pretreated OFMSW basis	Raw mass minus wet rejects, explicit dilution to source concentration
Oxygen stock used as annual demand	COD-based respiration plus annual mixing and pumping
Separator dry/wet denominator	All actual wet inlets charged and linked
Independent gas enhancement	Residual COD and carbon determine methane and CO_2
Full PHA despite 74% capture	Uniform capture followed by explicit extraction efficiency
Core/final coating ambiguity	2% final mass; predried core and water removal explicit
Missing/inconsistent residuals	Harvest and extraction returns to digestion; final liquid to treatment
Fixed 18-day heating period	Annual thermal services and working-volume losses
Avoided fertilizer as physical core	Actual compost mass separate from optional nutrient equivalents
Unverified source credit benefits	Reference zero material credits; optional coupled sensitivities

Table S10. Revised physical product and residual outputs. No allocated product footprint, agronomic equivalence or universal PET displacement is inferred.

Output, kg/y	SS-B	SS-PHA	OFMSW-B	OFMSW-PHA
Wet compost before coating allocation	806,398.51	739,456.09	28,467,554.86	23,591,865.77
Recovered dry PHA	0.00	4,254.11	0.00	849,272.45
Candidate final coated product	0.00	212,705.54	0.00	9,094,370.02
Remaining wet compost	806,398.51	364,243.52	28,467,554.86	7,549,397.05
Physical surplus PHA	0.00	0.00	0.00	667,385.05
Dewatering liquid assigned to treatment	18,070,195.83	62,857,867.15	792,985,109.38	4,349,606,691.51
Fixed solids in that liquid	55,552.01	56,018.16	1,498,186.69	1,533,884.92
Captured solvent output	0.00	80,019.82	0.00	3,421,302.00
Fugitive solvent air stream	0.00	808.28	0.00	34,558.61

Table S11. Thirty evaluated coupled cases. GWP difference is PHA integration minus its own baseline, kg CO_2 eq/t incoming wet waste. Counts refer to the eleven characterized totals within the stated model scope.

Case	SS GWP difference	OFMSW GWP difference	SS higher /11	OFMSW higher /11
1 Reference	2.69×10^2	4.45×10^2	11	11
2 PHA formation -25%	2.37×10^2	4.46×10^2	11	11

Case	SS GWP difference	OFMSW GWP difference	SS higher /11	OFMSW higher /11
3 PHA formation +25%	3.00×10^2	4.44×10^2	11	11
4 Capture 60%	2.44×10^2	4.15×10^2	11	11
5 Capture 90%	2.95×10^2	4.77×10^2	11	11
6 Extraction 70%	2.40×10^2	4.43×10^2	11	11
7 Extraction 100%	2.83×10^2	4.46×10^2	11	11
8 Low yield and recovery	2.00×10^2	4.16×10^2	11	11
9 High yield and recovery	3.50×10^2	4.78×10^2	11	11
10 Aeration 0.5x	2.67×10^2	4.41×10^2	11	11
11 Aeration 2x	2.73×10^2	4.53×10^2	11	11
12 Equipment 0.5x	2.32×10^2	3.70×10^2	11	11
13 Equipment 2x	3.41×10^2	5.94×10^2	11	11
14 Low AD conversion	2.79×10^2	4.96×10^2	11	11
15 High AD conversion	2.57×10^2	4.20×10^2	11	11
16 Low compost conversion	2.72×10^2	4.67×10^2	11	11
17 High compost conversion	2.65×10^2	4.22×10^2	11	11
18 CHP 38% / 38%	2.83×10^2	4.67×10^2	11	11
19 Dilute coating solution 2%	3.92×10^2	5.93×10^2	11	11
20 Methane leakage 3%	2.69×10^2	4.44×10^2	11	11
21 No heat recuperation	3.20×10^2	5.35×10^2	11	11
22 Concentrated coating solution 10%	2.27×10^2	3.95×10^2	11	11
23 Residual treatment 2x	2.66×10^2	4.39×10^2	11	11
24 NaClO active mass interpretation	2.65×10^2	4.36×10^2	11	11
25 PET 0.72	2.69×10^2	4.30×10^2	11	11
26 Peat and 50% nutrient credits	2.69×10^2	4.46×10^2	11	11
27 All source substitution upper case	2.70×10^2	4.32×10^2	11	11
28 Dry reject 80% TS	2.69×10^2	4.08×10^2	11	11
29 Wet reject 20% TS	2.69×10^2	4.63×10^2	11	11
30 Combined unfavorable	2.75×10^2	5.69×10^2	11	11

Table S12. Reference foreground conservation checks. Residuals are kg/y or kg COD/y; absolute numerical tolerance is 0.001. The checks concern the declared lumped foreground and separate ancillary ledgers, not measured elemental or plant validation.

Closure residual	SS-B	SS-PHA	OFMSW-B	OFMSW-PHA
Wet mass	6.91×10^{-10}	3.34×10^{-9}	-1.68×10^{-7}	-3.97×10^{-7}
Water with reaction water	0	0	0	9.54×10^{-7}
Dry solids with conversion	0	-2.33×10^{-10}	0	0
Fixed solids	0	2.91×10^{-11}	0	0
COD	-1.16×10^{-10}	8.73×10^{-11}	-3.73×10^{-9}	-1.86×10^{-9}
Surrogate carbon	-7.28×10^{-12}	7.28×10^{-12}	-9.31×10^{-10}	-6.52×10^{-9}

Closure residual	SS-B	SS-PHA	OFMSW-B	OFMSW-PHA
Polymer allocation	0	0	0	0

Replication and limitations

The four foreground configurations use a shared, coupled inventory model. Material, COD and energy balances are applied consistently across process stages, and the thirty sensitivity cases recalculate dependent flows. Supplementary Tables S4–S12 provide annual energy, assumptions, sensitivity ranges, reference-flow conventions, characterization provenance, principal model revisions, product and residual outputs, case results and conservation checks.

The numerical background coefficients and source inventory values are supplied to support replication; dataset identifiers, complete geography/system-model metadata and the database-version mapping are unavailable. Residual-treatment and gas-cleaning waste handling are proxies. Common reject disposal after transport is excluded consistently within each pair. Agricultural use is outside the quantified boundary, and unverified material credits are zero in the reference. Detailed nitrogen/sulfur/chlorine speciation and complete direct solvent-emission characterization remain limitations. Numerical conservation of the declared foreground is not process validation.

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