

Energy Production from Cattle Manure within a Life Cycle Assessment Framework: Statistical Optimization of Co-Digestion, Pretreatment, and Thermal Conditions

A. Albalade-Ramirez^{1,2}, M.M. Alcalá-Rodríguez¹, L.R. Miramontes-Martínez¹, A. Padilla-Rivera⁴, A. Estrada-Baltazar³, B.N. López-Hernández^{1,2}, P. Rivas-García^{1,2*}

¹*Departamento de Ingeniería Química, Facultad de Ciencias Químicas, Universidad Autónoma de Nuevo León. Av. Universidad S/N, Cd. Universitaria, zip 64451, San Nicolás de los Garza, Nuevo León, Mexico.*

²*Centro de Investigación en Biotecnología y Nanotecnología, Facultad de Ciencias Químicas, Universidad Autónoma de Nuevo León. Parque de Investigación e Innovación Tecnológica, km 10 Highway to the International Airport Mariano Escobedo, zip 66629 Apodaca, Nuevo León, Mexico.*

³*Departamento de Ingeniería Química, Instituto Tecnológico de Celaya, Av. Tecnológico y A. García Cubas S/N, C.P. 38010, Celaya, Guanajuato, Mexico.*

⁴*School of Architecture, Planning and Landscape, University of Calgary, 2500 University Drive NW, T2N 1N4, Calgary, Alberta, Canada.*

Corresponding author e-mail: pasiano.rivasgr@uanl.edu.mx

SUPPLEMENTARY MATERIAL

CONTAINS

Table S1. Characterization parameters for substrates and effluents.

Figure S1. Biochemical methane potential tests to assess the influence of CM pretreatment.

Table S2 Categorization of the fruit and vegetable waste collected at the supply center

Figure S2. Boundary diagram of CM recovery scenario in mono-digestion under mesophilic conditions.

Figure S3. Representative diagram of the Applikon ® bioreactor for the inoculum demethanization process.

Figure S4. Image of the Applikon ® bioreactor for the inoculum demethanization process.

Section S1. Life cycle inventory

Table S1. Characterization parameters for each process.

Parameter	Reference	Inoculum	Substrate	BMP effluents	Pretreatment effluents
pH	NMX-AA-25-1984	X	X		X
Humidity (%)	NMX-AA-034-SCFI- 2015	X	X		X
Total solids (%)	NMX-AA-034-SCFI- 2015	X	X		X
Volatile solids (% TS)	NMX-AA-034-SCFI- 2015	X	X		X
Ash (% TS)	NMX-AA-034-SCFI- 2015	X	X		X
Alkalinity (g CaCO ₃ L ⁻¹)	NMX-AA-036-SCFI- 2001	X	X	X	
Volatile fatty acids (g L ⁻¹)	NMX-AA-036-SCFI- 2001	X	X	X	
Cellulose (g g SV ⁻¹)	AOAC (1968) Vol. 51, No. 4.	X	X		X
Hemicellulose (g g SV ⁻¹)	AOAC (1968) Vol. 51, No. 4.	X	X		X
Lignin (g g SV ⁻¹)	AOAC (1968) Vol. 51, No. 4.	X	X		X
Total sugars (mg mL ⁻¹)	NMX-F-496-SCFI-2011	X	X		X
Total phenolic compounds (mg g ⁻¹)	NMX-AA-050-SCFI- 2001	X	X		X
Total nitrogen (mg g ⁻¹)	EPA-821-R-004			X	

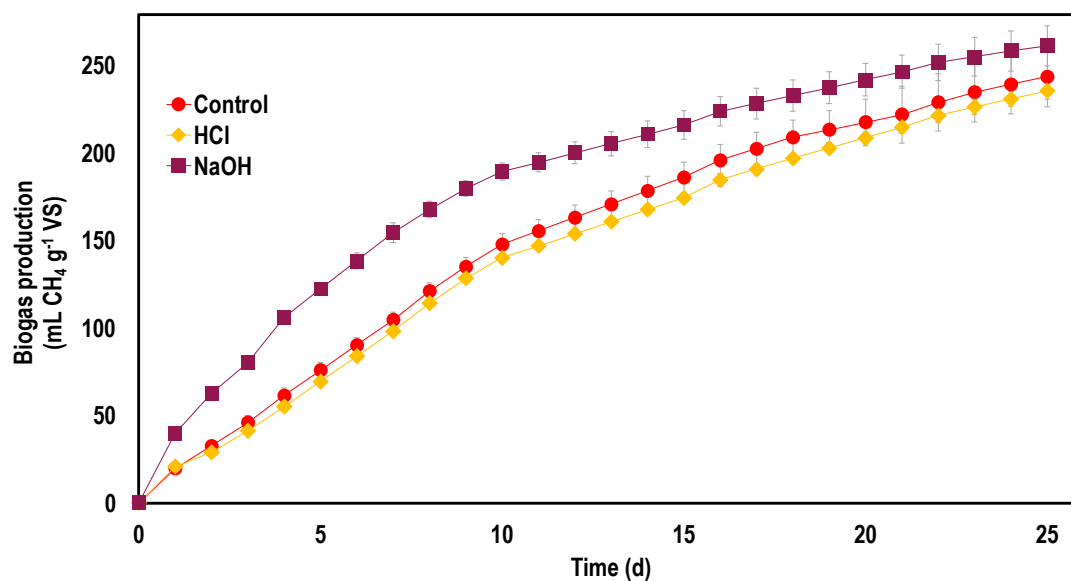


Figure S1. Methane yield for pretreatment selection study. The pretreatment process was conducted following the recommendations of Passos et al., (2017).

Table S2 Categorization of the fruit and vegetable waste collected at the supply center

FVW	% w w ⁻¹	FVW	% w w ⁻¹
Tomato	12.02	Cabbage	3.55
Mango	7.10	Pineapple	3.28
Banana	6.56	Broccoli	2.73
Apple	6.56	Cucumber	2.19
Watermelon	6.56	Beetroot	1.64
Green tomato	6.28	Celery	1.64
Green chilli pepper	6.28	Carrot	1.37
Onion	6.01	Pumpkin	0.82
Orange	5.74	Radish	0.82
Potato	5.19	Coconut Shell	0.55

Cantaloupe	4.37	Lemon	0.55
Avocado	4.37	Others	0.27
Prickly pear fruit	3.55		

FVW: Fruit and vegetable waste.

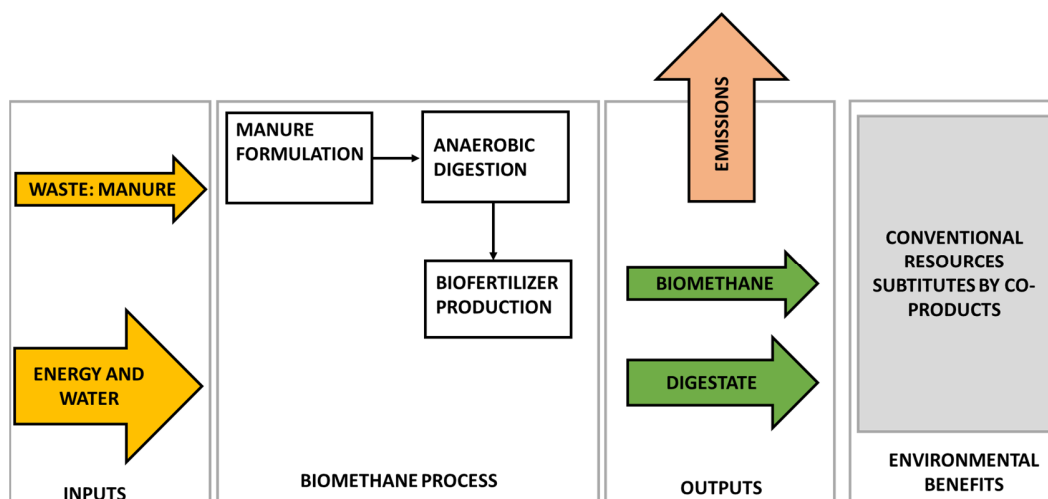


Figure S2. Boundary diagram of CM recovery scenario in mono-digestion under mesophilic conditions.

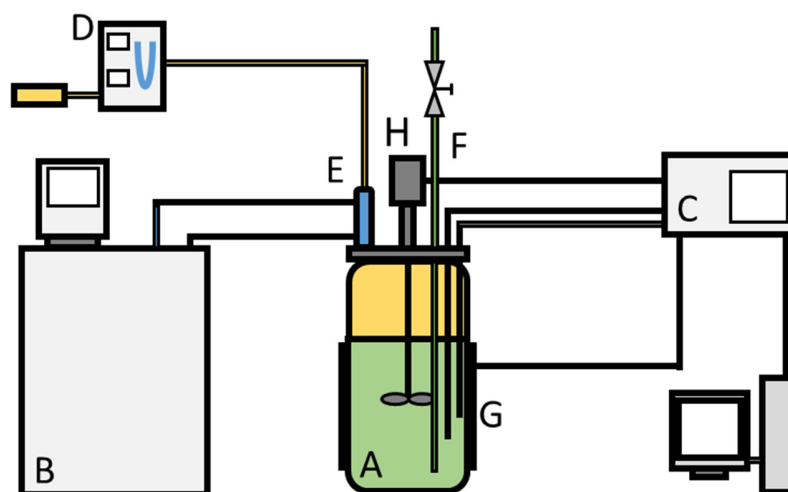


Figure S3. Representative diagram of the Applikon® bioreactor for the inoculum demethanization process. A) anaerobic digester B) temperature bath C) control panel D) biogas volumetric meter E) condenser F) valve for sampling G) heating mantle H) stirring motor.

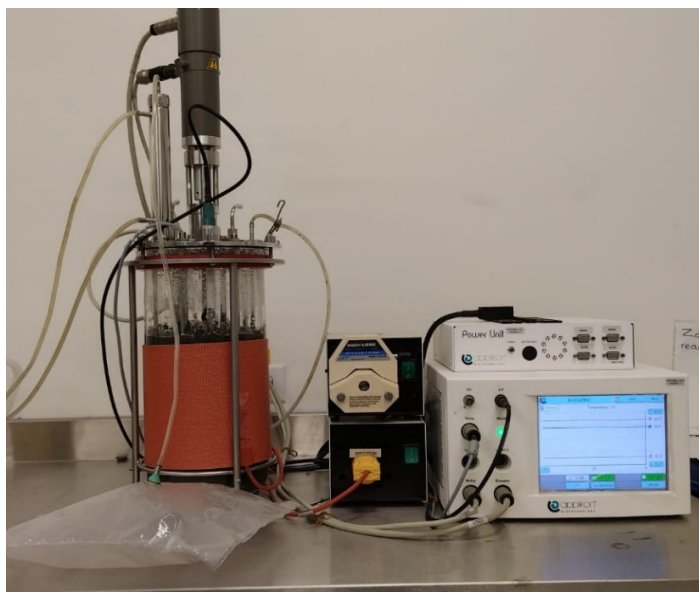


Figure S4. Image of the Applikon ® bioreactor for the inoculum demethanization process.

Section S1. Life cycle inventory.

Table E1.1		
<i>Pretreatment</i>		
<i>Substrate formulation</i>		
Distilled water	1.79	L/kgCM
<i>Chemical agent</i>		
NaOH	0.0012	kg/kgCM
<i>Heating</i>		
Electricity	473.08	kJ/kgCM
<i>Anaerobic Digestion</i>		
<i>Mixture</i>		
Inoculum	4.03	L/kgCM
FVW	1.29	kg/kgCM
<i>Heating</i>		
Electricity	85.10	kJ/kgCM
<i>Effluent</i>		
Digestate	8.06	L/kgCM
<i>Methane production</i>		
Methane	40.96	L/kg CM
CH ₄ emissions	0.0005	kg/kg CM
	0.26	
Electric production	958.68	kJ/kgCM
Heat production	516.21	kJ/kgCM
<i>Biofertilizer production</i>		
<i>Drying</i>		
Electricity	235.70	kJ/kgCM
N emitted as NH ₃	2.56E-08	kg/kgCM
N emitted as N ₂ O	2.99E-08	kg/kgCM
<i>Biofertilizer</i>		
Total Nitrogen	2.13E-05	kg/kgCM
Urea substitution	4.63E-05	kg/kgCM

Table E2.1		
<i>Pretreatment</i>		
<i>Substrate formulation</i>		
Distilled water	1.22	L/kgCM
<i>Chemical agent</i>		
NaOH	0.012	kg/kgCM
<i>Heating</i>		
Electricity	473.08	kJ/kgCM
<i>Anaerobic Digestion</i>		
<i>Mixture</i>		
Inoculum	4.033333333	L/kgCM
FVW	1.292735043	kg/kgCM
<i>Heating</i>		
Electricity	85.10177601	kJ/kgCM
<i>Effluent</i>		
Digestate	8.066666667	L/kgCM
<i>Methane production</i>		
Methane	64.5672	L/kg CM
		kg/kg
CH ₄ emissions	0.000922389	CM
Electric production	1435.328856	kJ/kgCM
Heat production	772.869384	kJ/kgCM
<i>Biofertilizer production</i>		
<i>Drying</i>		
Electricity	235.7017259	kJ/kgCM
N emitted as NH ₃	2.20108E-05	kg/kgCM
N emitted as N ₂ O	2.56792E-05	kg/kgCM
<i>Biofertilizer</i>		
Total Nitrogen	0.018342307	kg/kgCM
Urea substitution	3.97881E-05	kg/kgCM

Table E3.1		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	0.504132231	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.0012	̄ kg/kgCM
<u>Heating</u>		
Electricity	545.6187778	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.016666667	̄ L/kgCM
FVW	0	kg/kgCM
<u>Heating</u>		
Electricity	42.30090667	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	4.033333333	̄ L/kgCM
<u>Methane production</u>		
Methane	23.9832	̄ L/kg CM
		kg/kg
CH ₄ emissions	0.000342617	CM
Electric production	533.146536	kJ/kgCM
Heat production	287.078904	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄ kJ/kgCM
N emitted as NH ₃	7.16104E-06	kg/kgCM
N emitted as N ₂ O	8.35454E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.005967531	̄ kg/kgCM
Urea substitution	1.29448E-05	kg/kgCM

Table E4.1		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	0.504132231	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0822281	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.016666667	̄ L/kgCM
FVW	0	kg/kgCM
<u>Heating</u>		
Electricity	42.30090667	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	4.033333333	̄ L/kgCM
<u>Methane production</u>		
Methane	22.4316	̄ L/kg CM
		kg/kg
CH ₄ emissions	0.000320451	CM
Electric production	498.654468	kJ/kgCM
Heat production	268.506252	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	117.850863	̄ kJ/kgCM
N emitted as NH ₃	1.33421E-05	kg/kgCM
N emitted as N ₂ O	1.55658E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.011118453	̄ kg/kgCM
Urea substitution	2.41181E-05	kg/kgCM

Table E5.1

<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0822281	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	759.2747361	̄kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄L/kgCM
<u>Methane production</u>		
Methane	32.0304	̄L/kg CM
		kg/kg
CH ₄ emissions	0.000457577	CM
Electric production	712.035792	kJ/kgCM
Heat production	383.403888	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄kJ/kgCM
N emitted as NH ₃	2.03524E-05	kg/kgCM
N emitted as N ₂ O	2.37445E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.016960352	̄kg/kgCM
Urea substitution	3.67904E-05	kg/kgCM

Table E6.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	741.5976941	̄kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄L/kgCM
<u>Methane production</u>		
Methane	43.1256	̄L/kg CM
		kg/kg
CH ₄ emissions	0.00061608	CM
Electric production	958.682088	kJ/kgCM
Heat production	516.213432	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄kJ/kgCM
N emitted as NH ₃	2.33676E-05	kg/kgCM
N emitted as N ₂ O	2.72622E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.019472997	̄kg/kgCM
Urea substitution	4.22408E-05	kg/kgCM

Table E7.1

<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.504132231	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.0012	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0822281	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.016666667	̄ L/kgCM
FVW	0	kg/kgCM
<u>Heating</u>		
Electricity	376.8875733	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	4.033333333	̄ L/kgCM
<u>Methane production</u>		
Methane	18.486	̄ L/kg CM
CH ₄ emissions	0.000264086	kg/kg CM
Electric production	410.94378	
Heat production	221.27742	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	117.850863	
N emitted as NH ₃	7.08566E-06	kJ/kgCM
N emitted as N ₂ O	8.2666E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.005904715	kg/kgCM
Urea substitution	1.28085E-05	̄ kg/kgCM

Table E8.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.504132231	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0822281	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.016666667	̄ L/kgCM
FVW	0	kg/kgCM
<u>Heating</u>		
Electricity	376.8875733	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	4.033333333	̄ L/kgCM
<u>Methane production</u>		
Methane	23.4228	̄ L/kg CM
CH ₄ emissions	0.000334611	kg/kgCM
Electric production	520.688844	kJ/kgCM
Heat production	280.370916	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	117.850863	̄ kJ/kgCM
N emitted as NH ₃	9.04552E-06	kg/kgCM
N emitted as N ₂ O	1.05531E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.007537934	̄ kg/kgCM
Urea substitution	1.63513E-05	L/kgCM

Table E9.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.745442773	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0826375	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.688888889	̄L/kgCM
FVW	0.430911681	kg/kgCM
<u>Heating</u>		
Electricity	281.225543	̄kJ/kgCM
<u>Effluent</u>		
Digestate	5.377777778	̄L/kgCM
<u>Methane production</u>		
Methane	52.7408	̄L/kg CM
CH ₄ emissions	0.00075344	kg/kgCM
Electric production	1172.427984	kJ/kgCM
Heat production	631.307376	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	157.134484	̄kJ/kgCM
N emitted as NH ₃	1.24627E-05	kg/kgCM
N emitted as N ₂ O	1.45398E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010385599	̄kg/kgCM
Urea substitution	2.25284E-05	L/kgCM

Table E10.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.745442773	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0826375	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.688888889	̄L/kgCM
FVW	0.430911681	kg/kgCM
<u>Heating</u>		
Electricity	281.225543	̄kJ/kgCM
<u>Effluent</u>		
Digestate	5.377777778	̄L/kgCM
<u>Methane production</u>		
Methane	50.7392	̄L/kg CM
CH ₄ emissions	0.000724846	kg/kgCM
Electric production	1127.932416	kJ/kgCM
Heat production	607.348224	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	157.134484	̄kJ/kgCM
N emitted as NH ₃	1.61814E-05	kg/kgCM
N emitted as N ₂ O	1.88783E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.013484527	̄kg/kgCM
Urea substitution	2.92506E-05	L/kgCM

Table E11.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0066	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	422.188256	̄kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄L/kgCM
<u>Methane production</u>		
Methane	79.3968	̄L/kg CM
CH ₄ emissions	0.00113424	kg/kgCM
	0.00113424	
Electric production	1764.990864	kJ/kgCM
Heat production	950.379696	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄kJ/kgCM
N emitted as NH ₃	2.02017E-08	kg/kgCM
N emitted as N ₂ O	2.35686E-08	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	1.68347E-05	̄kg/kgCM
Urea substitution	3.65178E-08	L/kgCM

Table E12.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.50413223	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0066	̄kg/kgCM
<u>Heating</u>		
Electricity	473.082228	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.01666667	̄L/kgCM
FVW	0	kg/kgCM
<u>Heating</u>		
Electricity	209.59424	̄kJ/kgCM
<u>Effluent</u>		
Digestate	4.03333333	̄L/kgCM
<u>Methane production</u>		
Methane	38.91	̄L/kg CM
CH ₄ emissions	0.00055586	kg/kgCM
Electric production	864.9693	kJ/kgCM
Heat production	465.7527	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	117.850863	̄kJ/kgCM
N emitted as NH ₃	9.837E-06	kg/kgCM
N emitted as N ₂ O	1.1477E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.0081975	̄kg/kgCM
Urea substitution	1.7782E-05	L/kgCM

Table E13.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.745442773	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0066	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0826375	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.688888889	̄L/kgCM
FVW	0.430911681	kg/kgCM
<u>Heating</u>		
Electricity	56.69563494	̄kJ/kgCM
<u>Effluent</u>		
Digestate	5.377777778	̄L/kgCM
<u>Methane production</u>		
Methane	45.088	̄L/kg CM
CH ₄ emissions	0.000644114	kg/kgCM
Electric production	1002.30624	kJ/kgCM
Heat production	539.70336	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	157.134484	̄kJ/kgCM
N emitted as NH ₃	1.3116E-05	kg/kgCM
N emitted as N ₂ O	1.5302E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010930005	̄kg/kgCM
Urea substitution	2.37093E-05	L/kgCM

Table E14.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.745442773	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0066	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0826375	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.688888889	̄L/kgCM
FVW	0.430911681	kg/kgCM
<u>Heating</u>		
Electricity	505.755451	̄kJ/kgCM
<u>Effluent</u>		
Digestate	5.377777778	̄L/kgCM
<u>Methane production</u>		
Methane	34.5504	̄L/kg CM
CH ₄ emissions	0.000493577	kg/kgCM
Electric production	768.055392	kJ/kgCM
Heat production	413.568288	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	157.134484	̄kJ/kgCM
N emitted as NH ₃	1.3116E-05	kg/kgCM
N emitted as N ₂ O	1.5302E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010930005	̄kg/kgCM
Urea substitution	2.37093E-05	L/kgCM

Table E15.1		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	0.745442773	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.0066	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0826375	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	2.688888889	̄ L/kgCM
FVW	0.430911681	kg/kgCM
<u>Heating</u>		
Electricity	281.225543	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	5.377777778	̄ L/kgCM
<u>Methane production</u>		
Methane	56.1536	̄ L/kg CM
CH ₄ emissions	0.000802194	kg/kgCM
Electric production	1248.294528	kJ/kgCM
Heat production	672.158592	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	157.134484	̄ kJ/kgCM
N emitted as NH ₃	1.3116E-05	kg/kgCM
N emitted as N ₂ O	1.5302E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010930005	̄ kg/kgCM
Urea substitution	2.37093E-05	L/kgCM

Table E1.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.796867274	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.024	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄ L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	253.645016	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄ L/kgCM
<u>Methane production</u>		
Methane	41.16768	̄ L/kg CM
CH ₄ emissions	0.00058811	kg/kgCM
	0.26758992	
Electric production	963.323712	kJ/kgCM
Heat production	518.712768	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄ kJ/kgCM
N emitted as NH ₃	4.52276E-09	kg/kgCM
N emitted as N ₂ O	5.27655E-09	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	3.76897E-06	̄ kg/kgCM
Urea substitution	8.17563E-06	L/kgCM

Table E2.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄ L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	253.645016	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄ L/kgCM
<u>Methane production</u>		
Methane	51.1152	̄ L/kg CM
CH ₄ emissions	0.000730217	kg/kgCM
Electric production	1136.290896	kJ/kgCM
Heat production	611.848944	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄ kJ/kgCM
N emitted as NH ₃	4.52276E-06	kg/kgCM
N emitted as N ₂ O	5.27655E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.003768967	̄ kg/kgCM
Urea substitution	8.17563E-06	L/kgCM

Table E3.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	5.675072402	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.024	̄ kg/kgCM
<u>Heating</u>		
Electricity	570.1805556	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	10.08333333	̄ L/kgCM
FVW	5.170940171	kg/kgCM
<u>Heating</u>		
Electricity	634.26934	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	20.16666667	̄ L/kgCM
<u>Methane production</u>		
Methane	10.9344	̄ L/kg CM
CH ₄ emissions	0.000156206	kg/kgCM
Electric production	243.071712	kJ/kgCM
Heat production	130.884768	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄ kJ/kgCM
N emitted as NH ₃	1.20607E-05	kg/kgCM
N emitted as N ₂ O	1.40708E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010050579	̄ kg/kgCM
Urea substitution	2.18017E-05	L/kgCM

Table E4.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	3.399858727	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.081614	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	1.008333333	̄L/kgCM
FVW	5.170940171	kg/kgCM
<u>Heating</u>		
Electricity	63.41139576	̄kJ/kgCM
<u>Effluent</u>		
Digestate	2.016666667	̄L/kgCM
<u>Methane production</u>		
Methane	11.0844	̄L/kg CM
CH ₄ emissions	0.000158349	kg/kgCM
Electric production	246.406212	kJ/kgCM
Heat production	132.680268	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	58.92543148	̄kJ/kgCM
N emitted as NH ₃	1.20607E-06	kg/kgCM
N emitted as N ₂ O	1.40708E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.001005058	̄kg/kgCM
Urea substitution	2.18017E-06	L/kgCM

Table E5.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.024	̄kg/kgCM
<u>Heating</u>		
Electricity	473.081614	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	590.7314961	̄kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄L/kgCM
<u>Methane production</u>		
Methane	19.9248	̄L/kg CM
CH ₄ emissions	0.00028464	kg/kgCM
Electric production	442.928304	kJ/kgCM
Heat production	238.499856	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄kJ/kgCM
N emitted as NH ₃	4.52276E-06	kg/kgCM
N emitted as N ₂ O	5.27655E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.003768967	̄kg/kgCM
Urea substitution	8.17563E-06	L/kgCM

Table E6.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄ L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	573.0544541	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄ L/kgCM
<u>Methane production</u>		
Methane	16.9872	̄ L/kg CM
CH ₄ emissions	0.000242674	kg/kgCM
Electric production	377.625456	kJ/kgCM
Heat production	203.336784	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄ kJ/kgCM
N emitted as NH ₃	4.52276E-06	kg/kgCM
N emitted as N ₂ O	5.27655E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.003768967	̄ kg/kgCM
Urea substitution	8.17563E-06	L/kgCM

Table E7.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	29.46139719	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.024	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0871404	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	10.08333333	̄ L/kgCM
FVW	51.70940171	kg/kgCM
<u>Heating</u>		
Electricity	1477.249984	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	20.16666667	̄ L/kgCM
<u>Methane production</u>		
Methane	9.6504	̄ L/kg CM
CH ₄ emissions	0.000137863	kg/kgCM
Electric production	214.528392	kJ/kgCM
Heat production	115.515288	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	589.2543148	̄ kJ/kgCM
N emitted as NH ₃	1.20607E-05	kg/kgCM
N emitted as N ₂ O	1.40708E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010050579	̄ kg/kgCM
Urea substitution	2.18017E-05	L/kgCM

Table E8.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	29.46139719	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0871404	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	10.08333333	̄L/kgCM
FVW	51.70940171	kg/kgCM
<u>Heating</u>		
Electricity	1477.249984	̄kJ/kgCM
<u>Effluent</u>		
Digestate	20.16666667	̄L/kgCM
<u>Methane production</u>		
Methane	10.2564	̄L/kg CM
CH ₄ emissions	0.00014652	kg/kgCM
Electric production	227.999772	kJ/kgCM
Heat production	122.769108	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	589.2543148	̄kJ/kgCM
N emitted as NH ₃	1.20607E-05	kg/kgCM
N emitted as N ₂ O	1.40708E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.010050579	̄kg/kgCM
Urea substitution	2.18017E-05	L/kgCM

Table E9.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.951995479	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.024	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0846843	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	6.05	̄L/kgCM
FVW	2.585470085	kg/kgCM
<u>Heating</u>		
Electricity	633.4003484	̄kJ/kgCM
<u>Effluent</u>		
Digestate	12.1	̄L/kgCM
<u>Methane production</u>		
Methane	11.6944	̄L/kg CM
CH ₄ emissions	0.000167063	kg/kgCM
Electric production	259.966512	kJ/kgCM
Heat production	139.981968	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	353.5525889	̄kJ/kgCM
N emitted as NH ₃	7.23642E-06	kg/kgCM
N emitted as N ₂ O	8.44249E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.006030348	̄kg/kgCM
Urea substitution	1.3081E-05	L/kgCM

Table E10.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.951995479	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.012	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0846843	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	6.05	̄L/kgCM
FVW	2.585470085	kg/kgCM
<u>Heating</u>		
Electricity	633.4003484	̄kJ/kgCM
<u>Effluent</u>		
Digestate	12.1	̄L/kgCM
<u>Methane production</u>		
Methane	11.776	̄L/kg CM
CH ₄ emissions	0.000168229	kg/kgCM
Electric production	261.78048	kJ/kgCM
Heat production	140.95872	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	353.5525889	̄kJ/kgCM
N emitted as NH ₃	8.14097E-06	kg/kgCM
N emitted as N ₂ O	9.4978E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.006784141	̄kg/kgCM
Urea substitution	1.47161E-05	L/kgCM

Table E11.2		
<u>Pretreatment</u>		
<u>Substrate formulation</u>		
Distilled water	1.228063855	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0186	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0834562	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	4.033333333	̄L/kgCM
FVW	1.292735043	kg/kgCM
<u>Heating</u>		
Electricity	422.188256	̄kJ/kgCM
<u>Effluent</u>		
Digestate	8.066666667	̄L/kgCM
<u>Methane production</u>		
Methane	12.0048	̄L/kg CM
CH ₄ emissions	0.000171497	kg/kgCM
	0.000171497	
Electric production	266.866704	kJ/kgCM
Heat production	143.697456	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	235.7017259	̄kJ/kgCM
N emitted as NH ₃	4.52276E-09	kg/kgCM
N emitted as N ₂ O	5.27655E-09	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	3.76897E-06	̄kg/kgCM
Urea substitution	8.17563E-09	L/kgCM

Table E12.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	29.4613972	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.018	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.08714	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	10.0833333	̄ L/kgCM
FVW	51.7094017	kg/kgCM
<u>Heating</u>		
Electricity	1055.76799	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	20.1666667	̄ L/kgCM
<u>Methane production</u>		
Methane	12.7116	̄ L/kg CM
CH ₄ emissions	0.00018159	kg/kgCM
Electric production	282.578868	kJ/kgCM
Heat production	152.157852	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	589.254315	̄ kJ/kgCM
N emitted as NH ₃	1.2061E-05	kg/kgCM
N emitted as N ₂ O	1.4071E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.01005058	̄ kg/kgCM
Urea substitution	2.1802E-05	L/kgCM

Table E13.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	1.951995479	̄ L/kgCM
<u>Chemical agent</u>		
NaOH	0.018	̄ kg/kgCM
<u>Heating</u>		
Electricity	473.0846843	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	6.05	̄ L/kgCM
FVW	2.585470085	kg/kgCM
<u>Heating</u>		
Electricity	380.5363366	̄ kJ/kgCM
<u>Effluent</u>		
Digestate	12.1	̄ L/kgCM
<u>Methane production</u>		
Methane	15.8368	̄ L/kg CM
CH ₄ emissions	0.00022624	kg/kgCM
Electric production	352.052064	kJ/kgCM
Heat production	189.566496	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	353.5525889	̄ kJ/kgCM
N emitted as NH ₃	7.23642E-06	kg/kgCM
N emitted as N ₂ O	8.44249E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.006030348	̄ kg/kgCM
Urea substitution	1.3081E-05	L/kgCM

Table E14.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	1.951995479	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0186	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0846843	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	6.05	̄L/kgCM
FVW	2.585470085	kg/kgCM
<u>Heating</u>		
Electricity	886.2643603	̄kJ/kgCM
<u>Effluent</u>		
Digestate	12.1	̄L/kgCM
<u>Methane production</u>		
Methane	13.4752	̄L/kg CM
CH ₄ emissions	0.000192503	kg/kgCM
Electric production	299.553696	kJ/kgCM
Heat production	161.298144	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	353.5525889	̄kJ/kgCM
N emitted as NH ₃	8.14097E-06	kg/kgCM
N emitted as N ₂ O	9.4978E-06	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.006784141	̄kg/kgCM
Urea substitution	1.47161E-05	L/kgCM

Table E15.2		
Pretreatment		
<u>Substrate formulation</u>		
Distilled water	1.951995479	̄L/kgCM
<u>Chemical agent</u>		
NaOH	0.0186	̄kg/kgCM
<u>Heating</u>		
Electricity	473.0846843	kJ/kgCM
<u>Anaerobic Digestion</u>		
<u>Mixture</u>		
Inoculum	6.05	̄L/kgCM
FVW	2.585470085	kg/kgCM
<u>Heating</u>		
Electricity	633.4003484	̄kJ/kgCM
<u>Effluent</u>		
Digestate	12.1	̄L/kgCM
<u>Methane production</u>		
Methane	11.4832	̄L/kg CM
CH ₄ emissions	0.000164046	kg/kgCM
Electric production	255.271536	kJ/kgCM
Heat production	137.453904	kJ/kgCM
<u>Biofertilizer production</u>		
<u>Drying</u>		
Electricity	353.5525889	̄kJ/kgCM
N emitted as NH ₃	2.04372E-05	kg/kgCM
N emitted as N ₂ O	2.38434E-05	kg/kgCM
<u>Biofertilizer</u>		
Total Nitrogen	0.017031021	̄kg/kgCM
Urea substitution	3.69436E-05	L/kgCM