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Synergy in the Urban Solid Waste Management System in Malolos City, Philippines

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The paper demonstrates through system dynamics modelling how the following variables work together in the urban solid waste management (USWM) system: population, city income, public participation, composting and recycling, and greenhouse gas emissions. Malolos City, Philippines, is used as a case study for three ten-year model scenarios: (1) USWM with no composting and recycling, (2) USWM with an operational materials recovery and composting facility (MRCF), and (3) USWM with operational MRCF and incorporated effects of public participation towards solid waste management practices. The operation of the MRCF in Scenario 2 reduced total volume of disposed solid waste by about 25,000 tons but increased total expenses for solid waste management by about Php 37M. The incorporation of the effects of public participation in Scenario 3 further reduced the volume of disposed solid waste by about 103,900 tons; reduced the volume of generated solid waste by around 101,000 tons; and allowed the informal collection of 9,966 tons of recyclables. Estimates of CH_4 and CO_2 emissions also decreased in Scenario 3. The results revealed how composting and recycling and public participation affects the USWM through reduced waste volumes and increased savings.

Key words: system dynamics, urban solid waste

INTRODUCTION

Solid waste affects land, water, and air; it also has implications to human health. In 2050, it is anticipated that two-thirds of global population will live in cities (UN 2013). With growing population and continuous urbanization, waste generation is projected to increase – waste in Asia alone is estimated to reach 1B tons by 2030 (Okumura *et al.* 2013).

Solid waste management systems (SWMS) in developing cities are dominantly characterized by mixed collection, minimal recycling, and uncontrolled final disposal (UN Habitat 2010). SWMS in developing cities also focus primarily on collection and removal services: source collection, transport, and disposal (Wilson 2007). Collection and removal services constitute 80–95% of total city SWM budget (Guerrero *et al.* 2013).

Environmental quality suffers due to unsustainable solid waste management practices (Chandrappa and Das 2012, Chiemchaisri *et al.* 2007). Activities in waste storage, collection, transfer and transport, recycling and composting, and final disposal have impacts toward the air, water, and land. Chandrappa and Das (2012) present a comprehensive summary of the environmental impacts of different stages of waste management. The current solid waste management system in the Philippines contributes to human-induced

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greenhouse gas emissions – 11% of national total according to the Climate Change Commission of the Philippines (2010) – and to water pollution [*e.g.*, solid waste accounts for 7% of total Pasig River water pollution according to Gorme *et al.* (2010)]. Public spaces with unmanaged waste are breeding grounds for disease vectors (*e.g.*, Hoornweg & Bhada-tata 2012). The environmental risks of solid waste management can cause health risks (Bridges *et al.* 2000, Gorme *et al.* 2010, Mor *et al.* 2006). The current model is limited in that it measures environmental quality using greenhouse gas emissions only.

The complexity of solid waste management problems has stimulated interest in studies using different quantitative and qualitative approaches, particularly in system dynamics modeling (SDM). The SDM approach has been used to study fast-growing urban centers both in developed (*e.g.*, Dyson and Chang 2005) and developing (*e.g.*, Guzman *et al.* 2010) regions because through SDM, interactions among a variety of factors can be explored even with data scarcity issues (Dyson and Chang 2005).

Municipal Solid Waste Management in the Philippines

Average per capita waste generation in cities and provincial capitals in the Philippines is 0.50 kg/cap/day (NSWMC 2015). Municipal solid waste is composed of 52.31% biodegradables, 27.78% recyclables, 17.98% residual waste, and 1.93% special waste (NSWMC 2015). The Philippine law Republic Act 9003 or the "Ecological Solid Waste Management Act of 2000" envisions a "systematic, comprehensive, and ecological solid waste management program." City governments are only mandated to collect non-recyclable materials and special wastes; however, because of budget constraints, the City Government of Malolos provides financial assistance to barangays struggling to perform mandated responsibilities.

Solid waste management research in the Philippines covers technical and socio-demographic themes, including: compliance with laws and ordinances (*e.g.*, Bernardo 2008, Irene 2014, Premakumara *et al.* 2014); implementation of low-cost technologies for composting and recycling (*e.g.*, Paul *et al.* 2012); and assessment of knowledge, attitudes, and practices of citizens and officials (*e.g.*, Del Mundo *et al.* 2009, Macawile and Su 2009, Tatlonghari and Jamias 2010). System dynamics modelling can incorporate the interrelated themes of solid waste management, but only a few studies in the Philippine context have been undertaken (*e.g.*, Guzman *et al.* 2010).

Conceptual Framework

The paper demonstrates the synergy in the interrelationships among solid waste management, population, city budget, environmental quality (measured in greenhouse gas emissions), marketability of recovered waste, and public participation (of waste generators). The synergy is characterized through exploring the intersections of economy, environment, and society in the USWM (Figure 1).

An ecological solid waste management system (ESWMS) considers societal influences, primary of which are population and existing laws. The characteristics of the population, also influenced by current economy, affects waste generation and composition. Developing cities experience increasing waste generation due high population growth, improving living standards, and changing activities (*e.g.*, Dyson and Chang 2005, Sufian and Bala 2007, Tanaka 2007). Institutional and commercial centers generate mostly plastic and paper waste (*e.g.*, Al-Salem *et al.* 2009), while residential centers generate mostly food and yard waste (*e.g.*, Guzman *et al.* 2010). Different waste generation and composition scenarios affect the environment differently. Laws and institutions set rules about solid waste and public participation in USWM. For example, providing markets for compost and recyclables will likely encourage composting and recycling. Changes in regulations for manufacturing *e.g.*, packaging standards, will change composition and volume of generated waste.

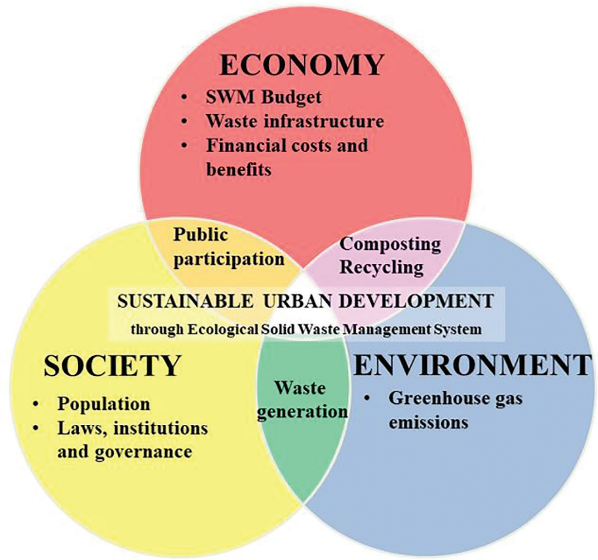

Figure 1. Conceptual framework of an ecological solid waste management system.

Urban environmental quality can be measured using indicators for water, land, soil, and air. The model uses primary greenhouse gases – CH_4, CO_2, and N_2O – to measure environmental quality in different waste management scenarios. Urban economy is complex, so the model uses city budget plus capital and operation costs and benefits to demonstrate economic affordability of the ESWMS. An efficient waste infrastructure system (*e.g.*, collection equipment, disposal and recovery facilities, roads) needs capital investment – thus, its implementation would be impossible without sufficient financial budget. Waste management costs and benefits, however, are not contained to the economy – these also have societal and environmental impacts. Recycling can give additional income to the community, inducing public participation while diverting waste from direct disposal.

An ESWMS, similar to the integrated solid waste management system (ISWMS) of Tammemagi (1999), seeks to "maximize the useful life of the resources" (Tammemagi 1999) and satisfy environmental effectiveness, social acceptability, and economic affordability (Marshall and Farahbakhsh 2013).

The participation of waste generators is an evidence of the social acceptability and behavior change towards ESWMS (*e.g.*, Rahardyan *et al.* 2004, Shaw and Maynard 2008), reducing waste generation and increasing the possibility of proper waste segregation, waste recovery (*e.g.*, Dyson and Chang 2005, Jacobi 2002, Lavee 2007) and waste disposal (*e.g.*, Troschinetz and Mihelcic 2009).

MATERIALS AND METHODS

System Dynamics Model

Flow of solid waste material. Figure 2 illustrates the framework of Philippine urban solid waste management based on various literature (EcoGov 2011, Guerrero *et al.* 2013, Guzman *et al.* 2010, Magalang 2014, Marshall and Farahbakhsh 2013, Wilson *et al.* 2012). Four final destinations are possible for solid waste in the current waste management system: informal collection, waste diversion, waste disposal, or unmanaged waste.

Households are assumed to perfectly segregate generated waste according to composition: recyclables, compostables, residuals, and special waste. When a barangay is unable to manage solid waste, the City is relayed with the responsibility to collect all generated waste. Special waste is directly brought to the disposal site; the rest undergoes the whole waste management system. *City waste collection* is the process in which the city formally collects generated waste. Remaining material after city waste collection either becomes unmanaged waste (litter) or managed when waste generators participate in SWM. Collection ability and public participation (in Scenario 3 only) influences waste collection. Remaining uncollected waste becomes *unmanaged solid waste* (which represents litter). Collected waste is brought to the final disposal site, unless it is diverted by another waste intervention – the current model uses a Materials Recovery and Composting Facility (MRCF) for waste diversion. The MRCF consists of the composting and recycling elements of the urban SWMS. Both composting and recycling practices have four stages: collection, processing, production, and sale. Waste is brought to the MRCF only if the MRCF is operational and funding is sufficient for current expenses; otherwise, waste is directly brought to the final disposal site. Waste is only considered "diverted" when it is converted into either compost or processed recyclables.

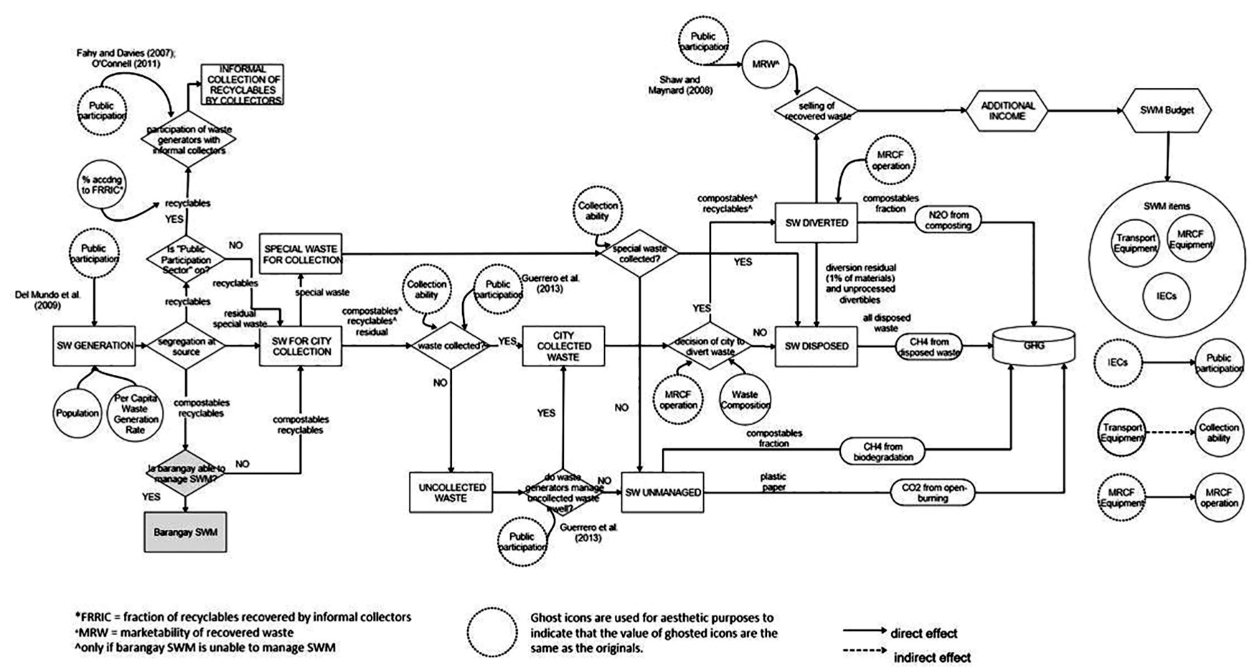

Figure 2. Framework of solid waste generation and management.

Informal collection is the volume of recyclable solid waste collected by door-to-door collectors – active only in Scenario 3. Recyclable waste that is collected informally is considered diverted from waste disposal. Waste disposal consists of: (1) collected waste that has been directly disposed; (2) residual from composting and recycling processes (assumed 1% of the material that is processed); and (3) waste transported to the MRCF but was not converted to compost and processed recyclables. The current model assumed that the city disposal site is a semi-aerobic managed solid waste disposal site (described in IPCC 2006).

Four sets of emissions were estimated: (1) CH_4 emission from disposed waste; (2) CH_4 emission from biodegradation of compostable fraction of unmanaged waste; (3) N_2O emission from composting; and (4) CO_2 emission from open-burning of plastic and paper fraction of unmanaged waste. All emission estimates assumed waste volumes in wet weight.

Model structure. The system dynamics model, constructed using STELLA (iseesystems.com), consists of eleven sectors (Table 1). Appendix I shows the stock and flow structure of the model. Appendix II contains detailed descriptions of all model variables. Three SWM items are identified (Table 2); each item is represented by equations similar to Equation 1.

$$Fund_i\,(t) = Fund_i\,(t-dt) + (budget\ inflow_i - expenses\ outflow_i) * dt \quad (1)$$

where: Fundi = available fund for i SWM item

budget $inflow_i$ = SWM Fund*ALLOCATION FOR i SWM item

expenses $outflow_i$ = respective expenses formula for i SWM item

Public participation. The current model defines public participation as the involvement of waste generators in different stages of waste management. The activated participation of waste generators in Scenario 3 is expected to (1) reduce per capita waste generation rate, (2) activate participation of waste generators with informal collectors of recyclables, (3) add value to collection ability for formal waste collection, (4) activate management of waste generators of waste uncollected by the city, and, (5) add value to the marketability of recovered waste. The *effect of public participation* converter (Table 3) encapsulates the additional effects of the participation of waste generators.

Marketability of recovered waste. Marketability of recovered waste (*mrw)* is the likelihood of selling recovered waste, which is expected to increase with the same rate as effect of public participation. *MRW* is expected to affect selling times and selling prices of produced compost and processed recyclables. Table 4 summarizes the corresponding selling prices and selling times for respective *mrw* converter values.

Greenhouse gas emissions. Three sets of emission estimates were evaluated: (1) total CH_4 emission from disposed waste and organic portion of unmanaged waste, (2) total CO_2 emission from open-burning of plastic and paper contents of unmanaged waste, and (3) total N_2O from the compostable fraction of waste that underwent composting. Formulae were derived from IPCC (2006).

Table 1. Sectors of the system dynamics model.

Sector	Purpose
Population Sector	Contains constants for population, growth rate, and initial public participation
SWM Budget Sector	Encapsulates the influence of city income and budget for SWM to the urban SWMS
Waste Composition Constants Sector	Contains values of waste composition fraction of SW
Public Participation Sector	Encapsulates the change in collective public participation of waste generators due to changes in allocation for information, education, and communication campaigns (IECs)
Marketability of Recovered Waste Sector	Encapsulates the level of acceptance for recovered waste in the market, measured as 0–100%
Solid Waste Management Sector	Encapsulates the material flow from waste generation to waste disposal, as well as the influence of the other sectors
Composting Sector	Contains the default structure of composting. Inputs for elements are in the Composting Facility sector.
Recycling Sector	Contains the default structure of recycling. Inputs for elements are in the Recycling Facility sector.
Jagna Composting Facility	Contains input values for the Composting Facility, based on the Jagna Facility in EcoGov (2011)
ADB Recycling Facility	Contains input values for the Recycling Facility, based on the Semi-automated Recycling Facility in ADB (2013)
GHG Emission Sector	Encapsulates the emission of CH_4,CO_2, and N_2O

Table 2. Solid waste management items in the study.

SWM Item	Funding and Expenses Represented
Transport equipment	City collection of waste and transport to waste diversion and disposal facilities
MRCF equipment	Construction and operation of the MRCF
Information, Education and Communication (IEC)	IEC campaigns aimed at raising public participation towards USWMS

Table 3. Range of values for effect of public participation converter.

Effect of public participation = GRAPH (*current public participation level*)

Based on authors' judgement, there is an assumption that a 1.0 increase in the level of public participation is equivalent to 25% increase in variables affected by public participation.

Current Public Participation Level	Effect of Public Participation
0	0.00
1	0.25
2	0.50
3	0.75
4	1.00

Table 4. Corresponding selling prices and selling prices for mrw values.

mrw[a]	Selling Price of Compost[b] (Php/50 kg Sack)	Selling Time for Compost[c]	Selling Price of Recyclables[d] (Php/kg)	Selling Time for Recyclables[c]
0.00	0	7 days	0	3 days
0.25	50	4 days	20	2 days
0.50	75	4 days	40	1 day
0.75	150	2 days	60	1 day
1.00	250	2 days	80	1 day

Notes:
[a]Marketability of recovered waste
[b]Based on experience of Maddela Quirino of Php 250 per 50 kg sack (EcoGov 2011)
[c]Authors' judgement
[d]Based on EMB recyclables selling price of Php 80/kg (EMB n/d)

Case Study

Brief profile of Malolos City. The system dynamics model was tested using Malolos City parameters (Table 5). Malolos City is the capital of the Province of Bulacan. A no-segregation, no-collection policy is implemented in the city (personal communication, City of Malolos Development Authority); the City General Services Office (CGSO) collects non-segregated waste on curbsides and brings it directly to the MRCF for separation and processing. It is assumed that CGSO budget (12% of city budget) is fully allotted for solid waste management. To imagine the worst-case, the model also assumes that all barangays are unable to manage solid waste and the City Government of Malolos City manages all generated waste.

The materials recovery and composting facility (MRCF) of Malolos City. Malolos City operates a five-hectare City Materials Recovery and Composting Facility (MRCF); however, baseline data was unavailable. To compensate for this data gap, the Materials Recovery and Composting Facility (Table 6) was derived from two references: for the composting facility, the experience of Jagna, Bohol described in EcoGov (2011); for the recycling facility, the Semi-Automated MRF Facility described in ADB (2013).

Model validation and scenarios. Table 7 compares the waste generation simulated in Scenario 1 with a computed projection of waste generation; the small difference between values mean the results of model simulations are acceptable. Similar to Sufian and Bala (2007), the behaviors of following key variables are examined in Scenario 1 to validate the system dynamics model: volumes of Disposed Waste, Unmanaged Waste, and Diverted Waste; expenses and savings in Transport Equipment, MRCF, and IECs (information, education, and communication campaigns); and volume of N_2O, CH_4, and CO_2 emissions.

The changes were compared in all three scenarios (Table 8). Scenario 1 simulates the Malolos City SWM without the MRCF to show the full potential of waste diversion in Scenario 2. Composting and recycling strategies are mandated by RA 9003 as a responsibility of the barangay through the establishment of MRCFs. Many barangays, however, are unable to construct and operate MRFs because of budget limitations. City governments, then, have the succeeding responsibility to establish a central MRCF for the city and its barangays. Scenario 2 measures the effect of establishing an MRCF in terms of: (1) the reduction in volume of waste disposed and

Table 5. Input parameters for Malolos City.

Variable Name	Input Value	Data Source/Reference
Initial Population (2014) (in persons)	264,182	City Government of Malolos 2014 Waste Analyses and Characterization Study (WACS)
Growth fraction	+1.19%	City Government of Malolos 2014 WACS
Yearly city budget(pesos)	Php 972,000,000.00	Rounded Malolos City 2015 Statement of General Fund (City Government of Malolos Website)
SWM budget allocation (percentage)	12%	2015 Budget for City General Services Office (City Government of Malolos Website)
Initial SW generation per capita rate (tons)	0.0036	City Government of Malolos 2014 WACS
Fraction of recyclables recovered by informal collectors	30%	Quezon City experience (Wilson *et al.* 2012)
Cost of collection and disposal per ton of SW (pesos)	1,322	City Government of Malolos, Personal interview
Initial Public Participation Level (unitless)	0	n/a
Initial Waste Composition	31.1% compostables, 19.5% recyclables 48.2% residual 1.19% special waste (10.42% plastic 7.21% paper)	City Government of Malolos 2014 WACS
Collection ability (percentage)	98%	City Government of Malolos 2014 WACS
Initial Marketability (percentage)	50%	Authors' judgement
TE MOOE FRACTION (additional cost for the maintenance and other operating expenses of transport equipment)	20%	Authors' judgement

Table 6. Characteristics of the composting facility and the recycling facility.

Parameter	Compost Being Processed Conveyor	Reference	Recyclables Being Processed Conveyor	Reference
Inflow limit	Infinite	Jagna, Bohol experience (EcoGov 2011)	Infinite	Semi-Automated MRF (ADB 2013)
Transit Time	45 days (represented by COMPOSTING TIME converter)		1 day (represented by RECYCLING TIME converter)	
Capacity	1.5 tons		15 tons	
Capital Cost	Php 550,000		Php 24.8M	
Operating Expenses	Php 20,000/mo		Php 2.5M/y	
Facility Count	1		1	
Facility Effectiveness	100%		100%	

GHG emissions, and (2) additional income. The MRCF Sector (along with the Recycling Facility and Composting Facility sectors), is turned on at the start of the simulation. The City realigns funds for transport equipment to satisfy capital costs of the MRCF. The MRCF becomes operational only in Year 2 to simulate planning and construction period. Scenario 3 simulates the effect of public participation of waste generators to the SWM. The Public Participation Sector is turned on to consider effects of public participation to the system. The City realigns funds for transport equipment to generate IECs.

Table 7. Computed vs. simulated waste generation.

Year	Volume of Waste Generation – Computation[a] (in Tons)	Volume of Waste Generation – Scenario 1 (in Tons)	Difference (in Tons)	Difference (in %)
1	34,713.51	34,920.31	206.29	0.59%
2	35,126.61	35,338.34	206.27	0.59%
3	35,544.61	35,761.37	206.22	0.58%
4	35,967.59	36,189.46	206.14	0.57%
5	36,395.61	36,622.68	206.03	0.57%
6	36,828.72	37,061.09	205.88	0.56%
7	37,266.98	37,504.74	205.71	0.55%
8	37,710.45	37,953.71	205.49	0.54%
9	38,159.21	38,408.05	205.25	0.54%
10	38,613.30	38,867.83	204.97	0.53%
TOTAL	**366,326.59**	**368,627.58**	**2,300.99**	**0.63%**

Notes:
Initial population = 264,182.00
Per annum growth rate = +1.19%
Per capita waste generation fraction = 0.36 kg/cap/day
[a]Population*(per capita waste generation/1000) x 365

Table 8. Summary of scenarios.

Scenario	Justifications	Sectors Turned On or Off					IPPL	SWM Budget Allocation		
		CS	RS	MRW	PP	Other Sectors		TE	MRCF	IEC
Baseline Run/Scenario 1: No composting and recycling strategies All SWM budget towards collection and disposal (Guerrero *et al.* 2013)	• To isolate the effects of waste diversion and public participation to the SWM, these were turned off.	OFF	OFF	OFF	OFF	ON	0	100%	0	0
Scenario 2: With active composting and recycling strategies, but no participation of waste generators.	• MRCF allocation is based on needed capital costs of CF and RF (Php 25,350,000).	ON	ON	ON	OFF	ON	0	80%	20%	0
Scenario 3: With active composting and recycling strategies, and with participation of waste generators.	• Portion of TE allocation is transferred to IEC allocation. • Waste generators only participate in SWM in Scenario 3. • Lowest level of public participation given to not overestimate.	ON	ON	ON	ON	ON	1	70%	20%	10%

Notes: CS – Composting Sector; RS – Recycling Sector; MRW – Marketability of Recovered Waste Sector; PP – Public Participation Sector; IPPL – Initial Public Participation Level; TE – Transport Equipment; MRCF – Material Recovery and Composting Facility; IEC – Information Education, and Communication Campaign

RESULTS

Figures 3 to 7 show ten-year trends for Scenarios 1, 2, and 3. The annual volumes of disposed waste in Scenario 1 are slightly lower than in Scenario 2 because of the MRCF. Scenario 3 has remarkable difference because of the effect of public participation. Only Scenario 3 exhibits changes in volumes of generated waste, informal collection of recyclables, and unmanaged waste; these changes are due the effect of public participation in the USWM (see Public Participation section). Scenarios 2 and 3 have equal volumes of diverted waste because the MRCF has similar characteristics in both scenarios. Simulation results of waste management for each scenario in Year 10 are in Table 9. Activating the MRCF in Scenario 2 reduced the volume of disposed waste (by 24,911 tons), yet ~7,400 tons of wastes remain unmanaged. Among the three scenarios, Scenario 3 generated the least volume of waste (~101,000 tons less), lowest percentage of unmanaged waste (0.01% in S3 vs 2% in S1 and S2), and least volume and percentage of disposed waste; it likewise diverted a total of ~13% of waste through composting and recycling (9.26%) and informal collection of recyclables (3.73%). Scenario 3 generated 69% more expenses than Scenario 1 but it also generated 25% more savings (Table 10). The increase in expenses is imputed to allocation to IECs;

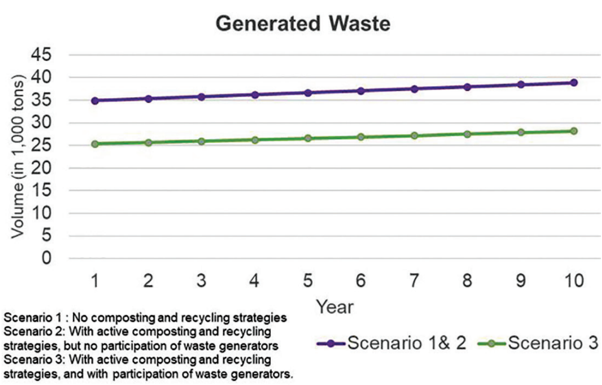

Figure 3. Ten-year values of generated waste.

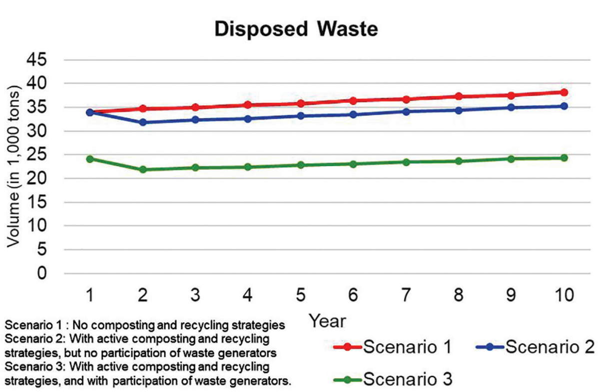

Figure 4. Ten-year values of disposed waste.

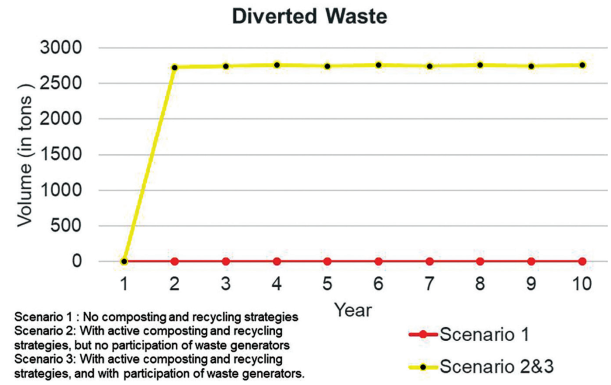

Figure 5. Ten-year values of diverted waste.

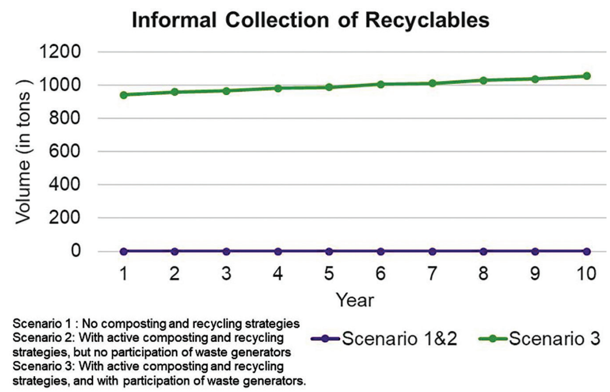

Figure 6. Ten-year values of informal collection of recyclables.

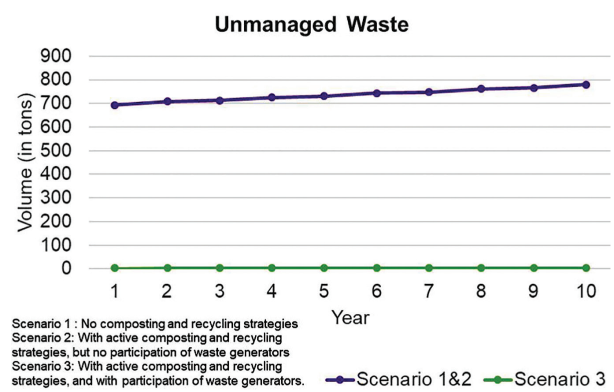

Figure 7. Ten-year values of unmanaged waste.

the increase in savings is attributed to the reinforcing effect of public participation towards marketability of waste and other waste management stages. Composting and recycling reduced CH_4 and CO_2 emission of the system but it also increased N_2O emission (Table 11); the reinforcing effect of public participation further reduced CH_4 emission and eliminated CO_2 emission (because there was negligible unmanaged waste percentage).

Table 9. Comparison of waste composition distribution in three scenarios in Year 10.

Scenario	TGSW[a]	TICW[b]	% of TGSW	TDivSW[c]	% of TGSW	TDisSW[d]	% of TGSW	TUSW[e]	% of TGSW	TWT[f]	% of TGSW
S1	368,627.58	0.00	0	0	0	361,045.07	97.94%	7,368.27	2.00%	214.24	0.06%
S2	368,627.58	0.00	0	24,721.50	6.71%	336,134.06	91.19%	7,368.27	2.00%	403.75	0.11%
S3	267,254.99	9,966.78	3.73%	24,721.50	9.26%	232,254.78	87.00%	31.78	0.01%	280.15	0.10%

Notes:
[a]Total Generated Solid Waste
[b]Total Informally Collected Waste (recyclables only)
[c]Total Diverted Solid Waste
[d]Total Disposed Solid Waste
[e]Total Unmanaged Solid Waste
[f]Total Waste in Transit

Table 10. Comparison of total SWM expenses and savings in three scenarios in Year 10.

Scenario	Total SWM Expenses (in Php)	Total SWM Savings (in Php)
S1	572,809,619.73	3,419,688,285.95
S2	609,676,674.59	4,354,495,021.04
S3	968,208,599.94	4,266,563,095.69
S2 vs S1	36,867,054.86	934,806,735.09
S3 vs S2	358,531,925.35	(87,931,925.35)
S3 vs S1	395,398,980.21	846,874,809.74

Table 11. Comparison of total greenhouse gas emission estimates in three scenarios in Year 10.

Scenario	Total CH_4Emission (in Tons)	Total CO_2 Emission (in Tons)	Total N_2O Emission (in Tons)
S1	10,263.98	920.60	0.00
S2	9,558.17	920.60	25,920.00
S3	6,580.70	3.97	25,920.00
S2 vs S1	(705.81)	-	25,920.00
S3 vs S2	(2,977.47)	(916.63)	-
S3 vs S1	(3,683.28)	(916.63)	25,920.00

DISCUSSION

Synergy in the Urban Waste Management System

The interlinkages and interactions among urban solid waste generation, urban solid waste management, population, city budget, marketability of recovered waste, public participation, composting and recycling, and GHG emissions defines the urban solid waste management system (Figure 8). Feedback effects in the system are primarily caused by public participation and waste diversion. Public participation is expected to decrease the uncertainty of recycling profitability (*e.g.*, Lavee 2007, Shaw and Maynard 2008) because citizens themselves will buy merchandise from recycled materials; in effect, public participation is expected to increase the marketability of recovered waste. The study showed how recycling sustained the synergy of the urban solid waste management system – recycling provided financial support for SWM items. With profit from recycling and composting, city budget increases and more budget is available for SWM items. Because of the operation of the MRCF, waste that previously goes directly to disposal is processed. The profit from selling recovered waste becomes additional SWM fund available for utilization in any of the four SWM items. Troschinetz and Mihelcic (2009) identified personnel education, waste collection and segregation, and government finances as the three biggest barriers to recycling in developing countries. The model simulations reveal how additional income from composting and recycling translate to effects in various elements of the USWMS because of increase in SWM fund. Additional SWM Fund could provide additional budget for personnel education through trainings and seminars, encourage the improvement of convenience of recycling and composting through the purchase of community bins, and enable the incentivization of local agencies for participation in sound waste management.

As a waste diversion strategy, composting has been found to be not as profitable as recycling (Eriksson *et al.* 2005, Tonjes and Mallikarjun 2013); however, it is practiced for its environmental benefits and reduced costs for collection and disposal (Tonjes and Mallikarjun 2013). In the current study, composting reduced the volume of unmanaged organic waste that may emit CH_4. Eriksson *et al.* (2005) found out that recycling is a more beneficial alternative to direct disposal than incineration and biological treatment in terms of larger financial returns and minimal pollution contribution. Malolos City can greatly benefit from a semi-automated recycling facility, with specifications similar to that described in ADB (2013).

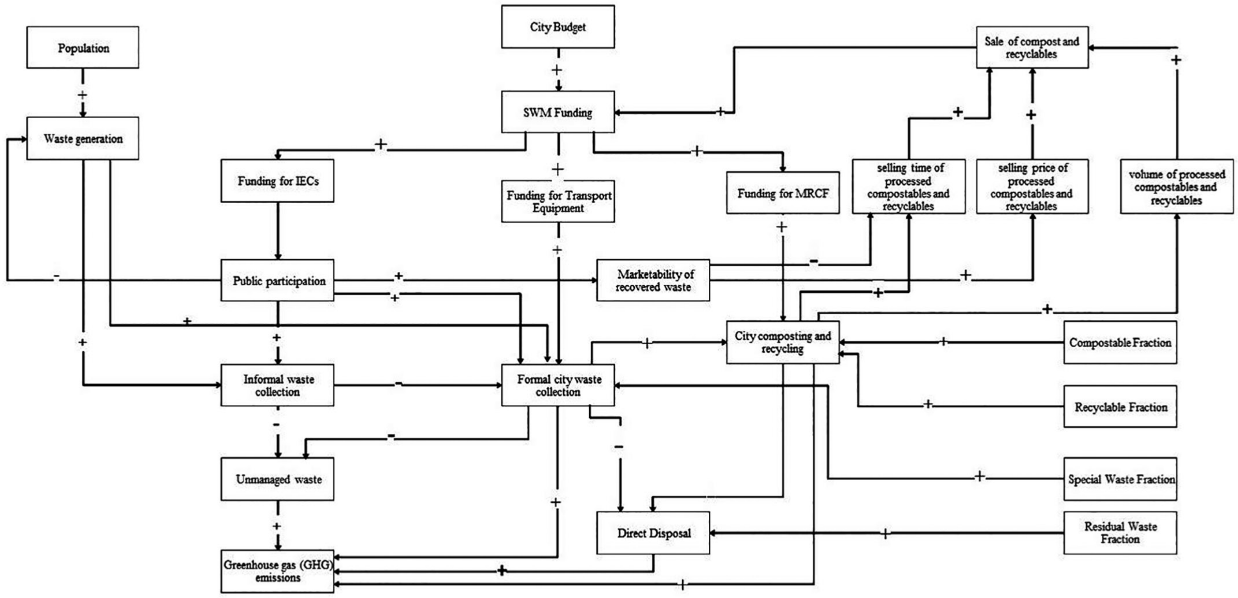

Figure 8. Causal loop diagram.

Reinforcing Effect of Public Participation

Scenario 3 yielded the following additional effects besides Scenario 2 improvements:

- reduced volume of total waste generation by 101,373 tons (–28% than in S1 and S2),
- reduced percentage of waste disposed (87% in S3 *vs.* 91% in S2),
- handling by the informal sector of 9,966.78 tons of recyclables (3.7% of total waste generation),
- reduced percentage of unmanaged waste (0.01% in S3 *vs.* 2% in S2), and
- further reduction of total CH_4 emission by ~2,977 tons and almost elimination of total CO_2 emission (3.97 tons remained).

Public participation in sustainable SWM practices decreases waste generation (*e.g.*, Bernardo 2008, Del Mundo *et al.* 2009). The decrease in volume of waste generation not only impacts waste collection, but also succeeding stages of SWM – diversion and disposal. Public participation provides opportunity for informal collection of recyclables. Public participation reinforces the effects of composting and recycling to the urban solid waste management system. A change in public participation level means a direct change towards formal waste collection, participation in informal waste collection, and marketability of waste; it also means an inverse change towards waste generation. The incorporation of public participation into the model provides reinforcing feedback into various aspects of the system. With public participation active, the income from composting and recycling are translated into effects to waste generation, collection, and diversion.

Marketability of recovered waste (MRW) is a function of public participation. Additional SWM fund from composting and recycling income allows for realignment of funds from transport equipment to IECs. With public participation incorporated and increasing because of IEC funding, *mrw* value increases, selling time for recovered waste is reduced and selling price is increased. The selling of recovered waste is quickened. Because of decreased volumes of generated waste, the waste collection system needs to manage less waste. A portion of budget allocation for transport equipment and MRCF equipment – the two largest shares – can be transferred to funding for IECs. Additional funding for IECs is directly related to additional public participation points, which echoes effect in waste generation, informal collection, formal collection, and marketability of waste. Scenario 3 gives a snapshot of the quantified effect of public awareness on the additional income of the USWMS because of changes in mrw. The effect of public participation must be calibrated to increase precision in simulation results.

CONCLUSIONS

The constructed system dynamics model demonstrated the synergy in the urban solid waste management system through exhibiting the effect of waste diversion (composting and recycling) and public participation on the volume of disposed waste. Through waste diversion and public participation, the volume of disposed waste can be reduced with increased total savings. The application of the model to Malolos City quantified the value added by the incorporation of public participation – lower volumes of generated solid waste and disposed waste and higher total savings. The behaviors of key variables illustrate that the impact of allocating budget for technical improvements like composting and recycling facilities can be reinforced by allocating budget for increasing public participation towards solid waste management practices.

Many variable relationships based on authors' judgement can be studied empirically: the relationship of marketability of recovered waste to selling prices of compost and recyclables; the effect of IECs to level of public participation; and the effect of public participation to different elements of the SWMS. The model can also be expanded to include other treatment options, particularly for managing residual waste and leachate treatment. Malolos City solid waste consists of 48.2% residual waste (City Government of Malolos 2014 WACS), which is expected to affect the lifespan of the city disposal site unless policy interventions are established.

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NOTE ON APPENDICES

The complete appendices section of the study is accessible at http://philjournsci.dost.gov.ph. A copy of the model is also accessible at http://philjournsci.dost.gov.ph.

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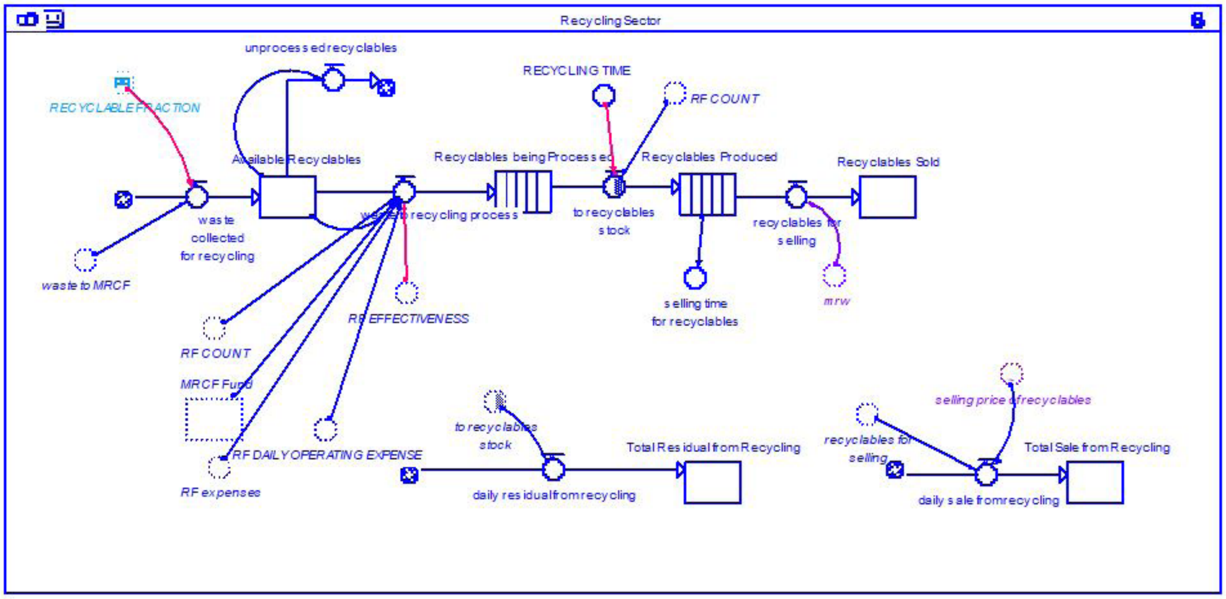
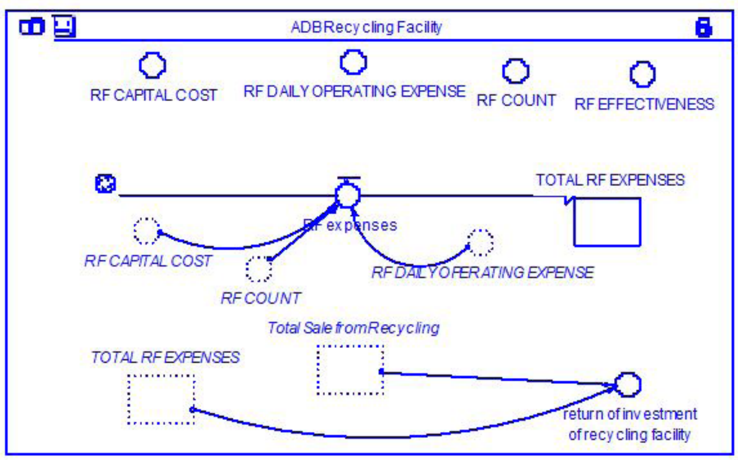
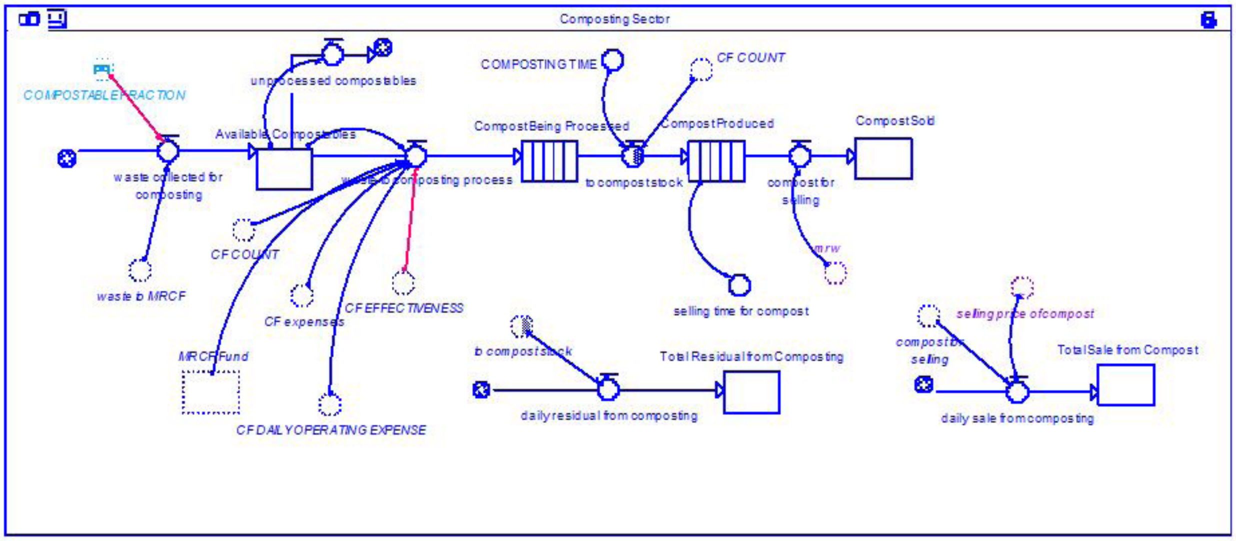
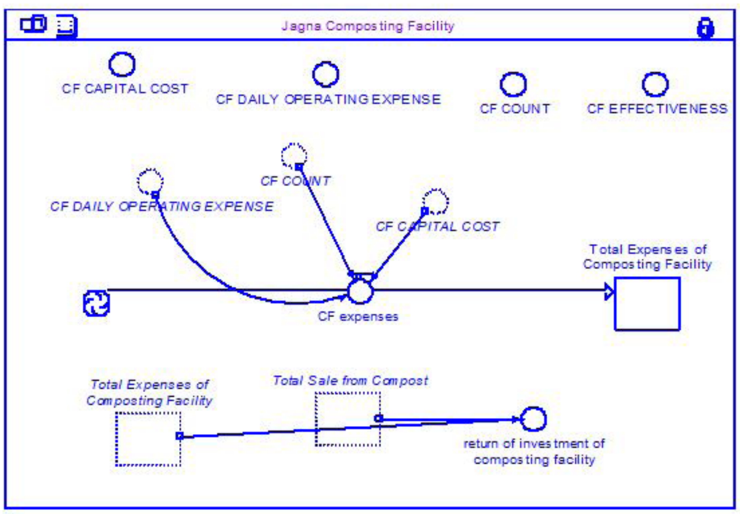
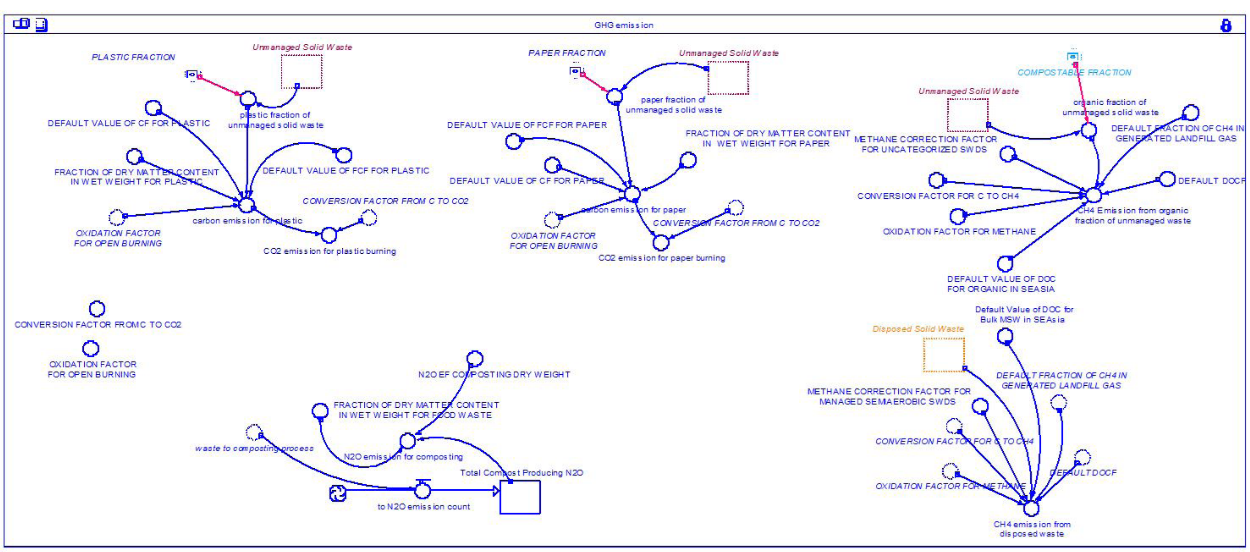
Appendix 1. Model Structure






Composting Sector
COMPOSTABLE FRACTION
unprocessed compostables
COMPOSTING TIME
CF COUNT
Available Compostables
Compost Being Processed
Compost Produced
Compost Sold
waste collected for composting
waste to composting process
to compost stock
compost for selling
CF COUNT
mrw
waste to MRCF
CF expenses
CF EFFECTIVENESS
selling time for compost
MRCF Fund
to compost stock
Total Residual from Composting
compost for selling
selling price of compost
Total Sale from Compost
daily residual from composting
daily sale from composting
CF DAILY OPERATING EXPENSE


Jagna Composting Facility
CF CAPITAL COST
CF DAILY OPERATING EXPENSE
CF COUNT
CF EFFECTIVENESS
CF COUNT
CF DAILY OPERATING EXPENSE
CF CAPITAL COST
Total Expenses of Composting Facility
CF expenses
Total Expenses of Composting Facility
Total Sale from Compost
return of investment of composting facility


GHG emission
PLASTIC FRACTION
Unmanaged Solid Waste
plastic fraction of unmanaged solid waste
DEFAULT VALUE OF CF FOR PLASTIC
FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PLASTIC
DEFAULT VALUE OF FCF FOR PLASTIC
CONVERSION FACTOR FROM C TO CO2
OXIDATION FACTOR FOR OPEN BURNING
carbon emission for plastic
CO2 emission for plastic burning
PAPER FRACTION
Unmanaged Solid Waste
paper fraction of unmanaged solid waste
DEFAULT VALUE OF FCF FOR PAPER
FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PAPER
DEFAULT VALUE OF CF FOR PAPER
carbon emission for paper
CONVERSION FACTOR FROM C TO CO2
OXIDATION FACTOR FOR OPEN BURNING
CO2 emission for paper burning
COMPOSTABLE FRACTION
Unmanaged Solid Waste
organic fraction of unmanaged solid waste
DEFAULT FRACTION OF CH4 IN GENERATED LANDFILL GAS
METHANE CORRECTION FACTOR FOR UNCATEGORIZED SWDS
CONVERSION FACTOR FOR C TO CH4
DEFAULT DOCF
CH4 Emission from organic fraction of unmanaged waste
OXIDATION FACTOR FOR METHANE
DEFAULT VALUE OF DOC FOR ORGANIC IN SEASIA
CONVERSION FACTOR FROM C TO CO2
OXIDATION FACTOR FOR OPEN BURNING
Default Value of DOC for Bulk MSW in SEAsia
Disposed Solid Waste
DEFAULT FRACTION OF CH4 IN GENERATED LANDFILL GAS
METHANE CORRECTION FACTOR FOR MANAGED SEMIAEROBIC SWDS
CONVERSION FACTOR FOR C TO CH4
DEFAULT DOCF
OXIDATION FACTOR FOR METHANE
CH4 emission from disposed waste
N2O EF COMPOSTING DRY WEIGHT
FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR FOOD WASTE
waste to composting process
N2O emission for composting
Total Compost Producing N2O
to N2O emission count

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
ADB Recycling Facility	TOTAL RF EXPENSES	Stock	Current amount of expenses for construction and operation of Recycling Facility (pesos)	TOTAL RF EXPENSES(t) = TOTAL RF EXPENSES(t - dt) + (RF expenses) * dt	ADB (2013)	N/A
ADB Recycling Facility	RF expenses	Flow	Daily expenses of Recycling Facility, including capital outlay and daily operating expenses (pesos)	PULSE(RF CAPITAL COST,365,0)+((PULSE(RF DAILY OPERATING EXPENSE,365,1)*RF COUNT))	ADB (2013)	N/A
ADB Recycling Facility	return of investment of recycling facility	Converter	Fraction of return of investment of Recycling Facility (unitless)	IF TOTAL RF EXPENSES > 0 THEN ((Total Sale from Recycling-TOTAL RF EXPENSES)/TOTAL RF EXPENSES)*100 ELSE 0	ADB (2013)	N/A
ADB Recycling Facility	RF CAPITAL COST	Converter	Capital outlay for the construction of the Recycling Facility (pesos)	Constant Value	ADB (2013)	ADB (2013)
ADB Recycling Facility	RF COUNT	Converter	Number of existing Recycling Facilities (unitless)	Constant Value	ADB (2013)	ADB (2013)
ADB Recycling Facility	RF DAILY OPERATING EXPENSE	Converter	Expected daily operating expenses of the Recycling Facility (pesos)	Constant Value/365	ADB (2013)	ADB (2013)
ADB Recycling Facility	RF EFFECTIVENESS	Converter	Measure of effectiveness of the Recycling Facility on a 0-100% scale (unitless)	Constant value between 0 and 1.	ADB (2013)	ADB (2013)
Composting Sector	Available Compostables	Stock	The current volume of waste in the MRCF available for composting (tons)	Available Compostables(t) = Available Compostables(t - dt) + (collected for composting - to composting - unprocessed compostables) * dt	EcoGov (2011)	N/A
Composting Sector	Compost Sold	Stock	The volume of compost sold (tons)	Compost Sold(t) = Compost Sold(t - dt) + (compost for selling) * dt	EcoGov (2011)	N/A
Composting Sector	Total Residual from Composting	Stock	The current volume of residual waste from composting process (tons)	Total Residual from Composting(t) = Total Residual from Composting(t - dt) + (daily residual from composting) * dt	EcoGov (2011)	N/A
Composting Sector	Total Sale from Compost	Stock	The current amount of money from selling produced compost (pesos)	Total Sale from Compost(t) = Total Sale from Compost(t - dt) + (daily sale from composting) * dt	EcoGov (2011)	N/A
Composting Sector	compost for selling	Flow	Process of selling produced compost (tons/day)	Outflow from the Compost Produced conveyor. Transit Time = 7, if mrw = 0; 4, if mrw ≤ 0.5; else 2.	EcoGov (2011)	N/A
Composting Sector	daily residual from composting	Flow	Residual compostable material after composting process; assumed 1% of every batch (tons/day)	to compost stock*0.01	EcoGov (2011)	N/A
Composting Sector	daily sale from composting	Flow	Amount of money from selling produced compost in 50kg sacks (pesos)	(compost for selling*1000)/50)*selling price of compost	EcoGov (2011)	N/A
Composting Sector	to compost stock	Flow	volume of compost that is added to saleable compost (tons/day)	The outflow from the Compost Being Processed conveyor.	EcoGov (2011)	N/A
Composting Sector	to composting	Flow	volume of compostables in the MRCF that undergo composting process; a function of RF characteristics	IF MRCF Fund > CF DAILY OPERATING EXPENSE AND CF expenses > 0 THEN Available Compostables*(CF EFFECTIVENESS*CF COUNT) ELSE 0	EcoGov (2011)	N/A
Composting Sector	unprocessed compostables	Flow	volume of compostables in the MRCF that do not undergo composting process because of MRCF capacity constraints (tons)	Remaining material in Available Compostables stock	EcoGov (2011)	N/A
Composting Sector	waste collected for composting	Flow	Material brought into the MRCF for composting (tons)	waste to MRCF*(COMPOSTABLE FRACTION/100)	EcoGov (2011)	N/A
Composting Sector	COMPOSTING TIME	Converter	Time for composting process to be completed and produce saleable compost (days)	Constant value	EcoGov (2011)	EcoGov (2011)
Composting Sector	Compost Being Processed	Stock - Conveyor	The current volume of waste undergoing composting process in the MRCF (tons)	Compost Being Processed(t) = Compost Being Processed(t - dt) + (to composting - to compost stock) * dt Transit Time is equal to the value of COMPOSTING TIME * CF COUNT. Capacity is 1.5 tons per day.	EcoGov (2011)	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Composting Sector	Compost Produced	Stock - Conveyor	The volume of compost produced (tons)	Compost Produced(t) = Compost Produced(t - dt) + (to compost stock - compost for selling) * dt Transit Time is equal to the value of mrw converter. Capacity is infinite.	EcoGov (2011)	N/A
GHG emission Sector	Total Compost Producing N2O	Stock	Current volume of compost that emits N2O	Total Compost Producing N2O(t) = Total Compost Producing N2O(t - dt) + (to N2O emission count) * dt	IPCC (2006)	N/A
GHG emission Sector	to N2O emission count	Flow	Process of accounting waste that undergoes composting and emits N2O	Equal to the value of to composting flow	IPCC (2006)	N/A
GHG emission Sector	carbon emission for paper	Converter	Carbon emission resulting from open-burning of Paper Fraction of SW (tons)	paper fraction of unmanaged solid waste*OXIDATION FACTOR FOR OPEN BURNING*FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PAPER*DEFAULT VALUE OF FCF FOR PAPER*DEFAULT VALUE OF CF FOR PAPER*DEFAULT VALUE OF CF FOR PAPER	IPCC (2006)	N/A
GHG emission Sector	carbon emission for plastic	Converter	Carbon emission resulting from open-burning of Plastic Fraction of SW (tons)	plastic fraction of unmanaged solid waste*FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PLASTIC*OXIDATION FACTOR FOR OPEN BURNING*DEFAULT VALUE OF FCF FOR PLASTIC*DEFAULT VALUE OF CF FOR PLASTIC*DEFAULT VALUE OF CF FOR PLASTIC	IPCC (2006)	N/A
GHG emission Sector	CH4 emission from disposed waste	Converter	CH4 emission resulting from disposed waste (tons)	CH4 Emission of Disposed Solid Waste = (Disposed Solid Waste * Methane Correction Factor * Degradable Organic Carbon * Fraction of DOC dissimilated * Fraction of CH4 in Landfill Gas* Conversion Factor of C to CH4- Recovered CH4)*(1 - Oxidation Factor)	IPCC (2006)	N/A
GHG emission Sector	CH4 Emission from organic fraction of unmanaged waste	Converter	CH4 emission resulting from organic fraction of unmanaged waste (tons)	CH4 Emission of Unmanaged Solid Waste = (Unmanaged Solid Waste * COMPOSTABLE FRACTION * Methane Correction Factor * Degradable Organic Carbon * Fraction of DOC dissimilated * Fraction of CH4 in Landfill Gas* Conversion Factor of C to CH4- Recovered CH4)*(1 - Oxidation Factor)	IPCC (2006)	N/A
GHG emission Sector	CO2 emission for paper burning	Converter	CO2 emission resulting from open-burning of Paper Fraction of SW	carbon emission for paper*CONVERSION FACTOR FROM C TO CO2	IPCC (2006)	N/A
GHG emission Sector	CO2 emission for plastic burning	Converter	CO2 emission resulting from open-burning of Plastic Fraction of SW	carbon emission for plastic*CONVERSION FACTOR FROM C TO CO2	IPCC (2006)	N/A
GHG emission Sector	CONVERSION FACTOR FOR C TO CH4	Converter	Conversion factor from C to CH4, according to IPCC 2006	16/12	IPCC (2006)	N/A
GHG emission Sector	CONVERSION FACTOR FROM C TO CO2	Converter	Conversion factor from C to CO2, according to IPCC 2006	44/12	IPCC (2006)	N/A
GHG emission Sector	DEFAULT DOCF	Converter	DOC dissimilated, according to IPCC 2006	0.5	IPCC (2006)	N/A
GHG emission Sector	DEFAULT FRACTION OF CH4 IN GENERATED LANDFILL GAS	Converter	Default fraction of CH4 in generated landfill gas, according to IPCC 2006	0.5	IPCC (2006)	N/A
GHG emission Sector	DEFAULT VALUE OF CF FOR PAPER	Converter	Default value for fraction of carbon in dry matter of Paper Fraction of SW, according to IPCC 2006	0.46	IPCC (2006)	N/A
GHG emission Sector	DEFAULT VALUE OF CF FOR PLASTIC	Converter	Default value for fraction of carbon in the dry matter of Plastic Fraction of SW	0.75	IPCC (2006)	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
GHG emission Sector	Default Value of DOC for Bulk MSW in SEAsia	Converter	Default Value of DOC for bulk MSW in Southeast Asia	0.17	IPCC (2006)	N/A
GHG emission Sector	DEFAULT VALUE OF DOC FOR ORGANIC IN SEASIA	Converter	Default Value of DOC for Organic in Southeast Asia	0.15	IPCC (2006)	N/A
GHG emission Sector	DEFAULT VALUE OF FCF FOR PAPER	Converter	Default value for fraction of fossil carbon in the total carbon of Paper Fraction of SW	0.01	IPCC (2006)	N/A
GHG emission Sector	DEFAULT VALUE OF FCF FOR PLASTIC	Converter	Default value for fraction of fossil carbon in the total carbon of Plastic Fraction of SW	1	IPCC (2006)	N/A
GHG emission Sector	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PAPER	Converter	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PAPER	0.9	IPCC (2006)	N/A
GHG emission Sector	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR FOOD WASTE	Converter	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR FOOD WASTE	0.4	IPCC (2006)	N/A
GHG emission Sector	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PLASTIC	Converter	FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR PLASTIC	1	IPCC (2006)	N/A
GHG emission Sector	METHANE CORRECTION FACTOR FOR MANAGED SEMIAEROBIC SWDS	Converter	METHANE CORRECTION FACTOR FOR MANAGED SEMIAEROBIC SWDS	0.5	IPCC (2006)	N/A
GHG emission Sector	METHANE CORRECTION FACTOR FOR UNCATEGORIZED SWDS	Converter	METHANE CORRECTION FACTOR FOR UNCATEGORIZED SWDS	0.6	IPCC (2006)	N/A
GHG emission Sector	N2O EF COMPOSTING DRY WEIGHT	Converter	N2O EF COMPOSTING DRY WEIGHT	0.6	IPCC (2006)	N/A
GHG emission Sector	N2O emission for composting	Converter	Current volume of N2O emission from the composting process (tons)	N2O emission from composting = (FRACTION OF DRY MATTER CONTENT IN WET WEIGHT FOR FOOD WASTE)* N2O EF COMPOSTING DRY WEIGHT* (Total Compost Producing N2O*1000)	IPCC (2006)	N/A
GHG emission Sector	organic fraction of unmanaged solid waste	Converter	Fraction of organic material in the unmanaged solid waste (unitless)	Unmanaged Solid Waste*(COMPOSTABLE FRACTION/100)	IPCC (2006)	N/A
GHG emission Sector	OXIDATION FACTOR FOR METHANE	Converter	OXIDATION FACTOR FOR METHANE	0	IPCC (2006)	N/A
GHG emission Sector	OXIDATION FACTOR FOR OPEN BURNING	Converter	OXIDATION FACTOR FOR OPEN BURNING	0.58	IPCC (2006)	N/A
GHG emission Sector	paper fraction of unmanaged solid waste	Converter	Fraction of paper material in the unmanaged solid waste (unitless)	Unmanaged Solid Waste*PAPER FRACTION	IPCC (2006)	N/A
GHG emission Sector	plastic fraction of unmanaged solid waste	Converter	Fraction of plastic material in the unmanaged solid waste (unitless)	Unmanaged Solid Waste*PLASTIC FRACTION	IPCC (2006)	N/A
Jagna Composting Facility	TOTAL CF EXPENSES	Stock	Current volume of expenses for construction and operation of Composting Facility (pesos)	Total Expenses of Composting Facility(t) = Total Expenses of Composting Facility(t - dt) + (CF expenses) * dt	EcoGov (2011)	N/A
Jagna Composting Facility	CF expenses	Flow	Daily expenses of Composting Facility, including capital outlay and daily operating expenses (pesos)	PULSE(CF CAPITAL COST,365,0)+((PULSE(CF DAILY OPERATING EXPENSE,365,1)*CF COUNT))	EcoGov (2011)	N/A
Jagna Composting Facility	CF CAPITAL COST	Converter	Capital outlay for the construction of the Composting Facility (pesos)	Constant value	EcoGov (2011)	EcoGov (2011)

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Jagna Composting Facility	CF COUNT	Converter	Number of existing Composting Facilities (unitless)	Constant value	EcoGov (2011)	EcoGov (2011)
Jagna Composting Facility	CF DAILY OPERATING EXPENSE	Converter	Expected daily operating expenses of the Composting Facility (pesos)	Constant value/30	EcoGov (2011)	EcoGov (2011)
Jagna Composting Facility	CF EFFECTIVENESS	Converter	Measure of effectiveness of the Composting Facility on a 0-1 scale (unitless)	Constant value between 0 and 1	EcoGov (2011)	EcoGov (2011)
Jagna Composting Facility	return of investment of composting facility	Converter	Fraction of return of investment of Composting Facility (unitless)	IF Total Expenses of Composting Facility > 0 THEN ((Total Sale from Compost-Total Expenses of Composting Facility)/Total Expenses of Composting Facility)*100 ELSE 0	EcoGov (2011)	N/A
Marketability of Recovered Waste Sector	mrw	Converter	Marketability of recovered waste: the level of acceptance for recovered waste in the market (unitless)	(INITIAL MARKETABILITY/100)+((INITIAL MARKETABILITY/100)*effect of public participation)	Shaw and Maynard (2008)	N/A
Marketability of Recovered Waste Sector	selling price of compost	Converter	The price at which sacks of produced compost are sold (pesos)	GRAPH (mrw)	EcoGov (2011)	N/A
Marketability of Recovered Waste Sector	selling price of recyclables	Converter	The price at which processed recyclables are sold (pesos)	GRAPH (mrw)	EMB (n/d)	N/A
Marketability of Recovered Waste Sector	INITIAL MARKETABILITY	Converter	Initial level of acceptance for recovered waste in the market (unitless)	Constant value between 0 and 100.	Lavee (2007); Shaw and Maynard (2008); Pieters (1991)	Authors' judgement
Population Sector	Population	Stock	Current population (persons)	Population(t) = Population(t - dt) + (growth) * dt	Guzman *et al.* (2010)	N/A
Population Sector	growth	Flow	Growth rate of population (persons/day)	Population*((GROWTH FRACTION/100)/365)	Guzman *et al.* (2010)	N/A
Population Sector	GROWTH FRACTION	Converter	Number of persons added to the population because of natural growth (persons)	Constant value	Guzman *et al.* (2010)	City Government of Malolos WACS (2014)
Population Sector	INITIAL PUBLIC PARTICIPATION LEVEL	Converter	Initial collective level of public participation of waste generators on the effects of solid waste management (unitless)	Constant value between 0 and 4.	Guerrero *et al.* (2013); Lavee (2007); Shaw and Maynard (2008); O'Connell (2001); Pieters (1991)	Authors' judgement
Public Participation Sector	current public participation level	Converter	The present collective level of public participation of waste generators towards the effects of USWM (unitless)	INITIAL PUBLIC PARTICIPATION LEVEL+additional public participation	Lavee (2007); Pieters (1991); Shaw and Maynard (2008)	N/A
Public Participation Sector	effect of allocation for IEC	Converter	Value added to another variable because of change in the allocation for IECs (unitless)	Equal to ALLOCATION FOR IEC/100)	Authors' judgement	N/A
Public Participation Sector	effect of public participation	Converter	Value added to another variable because of present public participation level (unitless)	GRAPH (current public participation level)	Authors' judgement	N/A
Public Participation Sector	additional public participation	Converter	Value of public participation added due to allocation for IECs (unitless)	(INITIAL PUBLIC PARTICIPATION LEVEL*effect of allocation for IEC)	Shaw and Maynard (2008); Lavee (2007); Pieters (1991)	N/A
Recycling Sector	Available Recyclables	Stock	The current volume of waste in the MRCF available for recycling (tons)	Available Recyclables(t) = Available Recyclables(t - dt) + (collected for recycling - to recycling - unprocessed recyclables) * dt	ADB (2013)	N/A
Recycling Sector	Total Residual from Recycling	Stock	The current volume of residual waste from recycling process (tons)	Total Residual from Recycling(t) = Total Residual from Recycling(t - dt) + (daily residual from recycling) * dt	ADB (2013)	N/A
Recycling Sector	Total Sale from Recycling	Stock	The current amount of money from selling processed recyclables (pesos)	Total Sale from Recycling(t) = Total Sale from Recycling(t - dt) + (daily sale from recycling) * dt	ADB (2013)	N/A
Recycling Sector	daily residual from recycling	Flow	Residual recyclable material after recycling process; assumed 1% of every batch (tons/day)	to recyclables stock*0.01	ADB (2013)	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Recycling Sector	daily sale from recycling	Flow	Amount of money from selling processed recyclables (pesos)	recyclables for selling*1000*selling price of recyclables	ADB (2013)	N/A
Recycling Sector	recyclables for selling	Flow	Process of selling processed recyclables (tons/day)	The outflow of Recyclables Produced conveyor. Transit Time = 3, if mrw = 0; 1, if mrw ≥ 0.5; else 2.	ADB (2013)	N/A
Recycling Sector	to recyclables stock	Flow	volume of compost that is added to saleable processed recyclables (tons/day)	The outflow from the Recyclables Being Processed conveyor.	ADB (2013)	N/A
Recycling Sector	unprocessed recyclables	Flow	volume of recyclables in the MRCF that do not undergo composting process because of MRCF capacity constraints (tons)	Remaining material in Available Recyclables stock	ADB (2013)	N/A
Recycling Sector	waste collected for recycling	Flow	Material brought into the MRCF for recycling (tons)	waste to MRCF*(RECYCLABLE FRACTION/100)	ADB (2013)	N/A
Recycling Sector	to recycling	Flow	volume of recyclables in the MRCF that undergo recycling process; a function of RF characteristics	IF MRCF Fund > RF DAILY OPERATING EXPENSE AND RF expenses > 0 THEN Available Recyclables*(RF EFFECTIVENESS*RF COUNT) ELSE 0	ADB (2013)	N/A
Recycling Sector	RECYCLING TIME	Converter	Time for recycling process to be completed and produce saleable recyclables (days)	Constant Value	ADB (2013)	ADB (2013)
Recycling Sector	Recyclables Sold	Stock	The volume of processed recyclables sold (tons)	Recyclables Sold(t) = Recyclables Sold(t - dt) + (recyclables for selling) * dt	ADB (2013)	N/A
Recycling Sector	Recyclables being Processed	Stock - Conveyor	The current volume of waste undergoing recycling process in the MRCF (tons)	Recyclables being Processed(t) = Recyclables being Processed(t - dt) + (waste to recycling process - to recyclables stock) * dt TRANSIT TIME is equal to the value of RECYCLING TIME Capacity is 15 tons per day.	ADB (2013)	N/A
Recycling Sector	Recyclables Produced	Stock - Conveyor	The volume of processed recyclables produced (tons)	Recyclables Produced(t) = Recyclables Produced(t - dt) + (to recyclables stock - recyclables for selling) * dt INIT Recyclables Produced = 0 TRANSIT TIME is equal to the value of mrw converter. Capacity is infinite.	ADB (2013)	N/A
Solid Waste Management Sector	Disposed Solid Waste	Stock	Current volume of waste in disposal facilities (tons)	Disposed Solid Waste(t) = Disposed Solid Waste(t - dt) + (daily city waste disposal + unprocessed waste from MRCF + direct disposal of special waste) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Diverted Solid Waste	Stock	Current volume of waste that completed diversion process (tons)	Diverted Solid Waste(t) = Diverted Solid Waste(t - dt) + (city waste diversion) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Generated Solid Waste	Stock	Current volume of waste generated by total population (tons)	Generated Solid Waste(t) = Generated Solid Waste(t - dt) + (daily waste generation - separation of special waste - informal collection of recyclables - daily waste for city collection) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Informal Collection of Solid Waste	Stock	Current volume of waste collected by informal collectors (tons)	Informal Collection of Solid Waste(t) = Informal Collection of Solid Waste(t - dt) + (informal collection of recyclables) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Solid Waste Management Sector	Solid Waste Available for Diversion	Stock	Current volume of waste in the MRCF that is available for composting and recycling (tons)	Solid Waste Available for Diversion(t) = Solid Waste Available for Diversion(t - dt) + (waste to MRCF - city waste diversion - unprocessed waste from MRCF) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Total Collected Solid Waste	Stock	Current volume of waste collected through formal collection (tons)	Total Collected Solid Waste(t) = Total Collected Solid Waste(t - dt) + (city waste collection + litter management - waste to MRCF - daily city waste disposal) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Total Special Waste	Stock	Current volume of special waste (tons)	Total Special Waste(t) = Total Special Waste(t - dt) + (separation of special waste) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Uncollected Solid Waste	Stock	Current volume of waste uncollected by the city (tons)	Uncollected Solid Waste(t) = Uncollected Solid Waste(t - dt) + (daily uncollected waste - litter management - daily rate of remaining uncollected city waste) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Unmanaged Solid Waste	Stock	Current volume of unmanaged waste (tons)	Unmanaged Solid Waste(t) = Unmanaged Solid Waste(t - dt) + (daily rate of remaining uncollected city waste + uncollected special waste) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	Waste for Formal Collection	Stock	Current volume of waste the city should collect (tons)	Waste for Formal Collection(t) = Waste for Formal Collection(t - dt) + (daily waste for city collection - daily city waste collection - daily uncollected waste) * dt	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	city waste diversion	Flow	Sum of produced compost and processed recyclables (tons/day)	to compost stock + to recyclables stock	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	city waste collection	Flow	Process of transporting waste collected by city (tons/day)	IF effect of public participation > 0 AND Transport Equipment Fund > 0 THEN Waste for Formal Collection*((COLLECTION ABILITY/100)+((COLLECTION ABILITY/100)*effect of public participation)) ELSE IF effect of public participation = 0 AND Transport Equipment Fund > 0 THEN Waste for Formal Collection*(COLLECTION ABILITY/100) ELSE 0	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	daily city waste disposal	Flow	Process of disposing city waste (tons/day)	Total Collected Solid Waste+daily residual from composting+daily residual from recycling	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Solid Waste Management Sector	daily rate of unmanaged waste	Flow	Waste that is left uncollected even after the second city collection (tons/day)	Total Collected Solid Waste+daily residual from composting+daily residual from recycling	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	daily uncollected waste	Flow	Waste that the city is unable to collect (tons/day)	Remaining material in Waste for Formal Collection stock	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	daily waste for city collection	Flow	Waste left for city collection after informal collection of recyclables and separation of special waste (tons/day)	(Generated Solid Waste*(COMPOSTABLE FRACTION/100))+(Generated Solid Waste*(RECYCLABLE FRACTION/100))+(Generated Solid Waste*(RESIDUAL FRACTION*100))	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	daily waste generation	Flow	Process of waste generation by current population (tons/day)	current SW generation per capita rate*Population	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guzman *et al.* (2010)	N/A
Solid Waste Management Sector	informal collection of recyclables	Flow	Process of recyclable waste being collected by informal collectors (tons/day)	IF effect of public participation >0 THEN (Generated Solid Waste*(RECYCLABLE FRACTION/100))*((FRACTION OF RECYCLABLES RECOVERED BY INFORMAL COLLECTORS/100) + ((FRACTION OF RECYCLABLES RECOVERED BY INFORMAL COLLECTORS/100)*effect of public participation)) ELSE 0	Magalang (2014); O' Connell (2011); Fahy and Davies (2007)	N/A
Solid Waste Management Sector	litter management	Flow	Process of management of uncollected waste (tons/day)	IF effect of public participation > 0 THEN Uncollected Solid Waste*effect of public participation ELSE 0	Magalang (2014); Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	separation of special waste	Flow	Process of separating special waste fraction of generated solid waste (tons/day)	Generated Solid Waste*(SPECIAL WASTE FRACTION/100)	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	unprocessed waste from MRCF	Flow	Waste that the MRCF is unable to process because of capacity limits; brought directly to disposal facilities (tons/day)	Remaining material in Solid Waste Available for Diversion stock	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A
Solid Waste Management Sector	waste to MRCF	Flow	Waste that is transported to the MRCF (tons/day)	IF MRCF Fund >0 and Transport Equipment Fund > 0 THEN Total Collected Solid Waste*(COLLECTION ABILITY/100) ELSE 0	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
Solid Waste Management Sector	direct disposal of special waste	Flow	disposal of special waste fraction collected (tons/day)	IF Transport Equipment Fund > 0 THEN Total Special Waste*(COLLECTION ABILITY/100) ELSE 0	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	uncollected special waste	Flow	Special waste that is uncollected (tons/day)	Remaining material in Total Special Waste stock	Magalang (2014); City Government of Malolos WACS (2014); Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	daily rate of remaining uncollected city waste	Flow	Remaining uncollected solid waste that is unmanaged because of insufficient litter management (tons/day)	Remaining material in Uncollected Solid Waste stock	Magalang (2014); City Government of Malolos WACS (2014); personal communication with City Environmental Specialist; Guerrero *et al.* (2013)	N/A
Solid Waste Management Sector	COLLECTION ABILITY	Converter	Fraction of collected material that is transferred to the next process (unitless)	Constant value between 0 and 100.	Magalang (2014); City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Solid Waste Management Sector	current SW generation per capita rate	Converter	Current volume of waste generated by a person (tons/day)	IF effect of public participation > 0 THEN (INITIAL SW GENERATION PER CAPITA RATE/1000)-((INITIAL SW GENERATION PER CAPITA RATE/1000)*effect of public participation) ELSE INITIAL SW GENERATION PER CAPITA RATE/1000	Del Mundo *et al.* (2009)	N/A
Solid Waste Management Sector	FRACTION OF RECYCLABLES RECOVERED BY INFORMAL COLLECTORS	Converter	Fraction of recyclable waste that informal collectors can collect (unitless)	Constant value between 0 and 100.	Magalang (2014); Wilson *et al.* (2012)	Wilson *et al.* (2012)
Solid Waste Management Sector	INITIAL SW GENERATION PER CAPITA RATE	Converter	Starting volume of waste generated by a person (tons/day)	Constant value	Del Mundo *et al.* (2009)	City Government of Malolos WACS (2014)
SWM Budget	City Budget	Stock	The annual amount of budget for the City (pesos)	City Budget(t) = City Budget(t - dt) + (yearly budget inflow - SWM budget inflow) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	IEC Fund	Stock	The current amount available for funding information education and communication campaigns for solid waste management practices (pesos)	IEC Fund(t) = IEC Fund(t - dt) + (to IEC fund - IEC expenses) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	MRCF Fund	Stock	The current amount available for funding the MRCF (pesos)	MRCF Fund(t) = MRCF Fund(t - dt) + (to MRCF fund - MRCF expenses) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	SWM Expenses	Stock	The total amount of SWM expenses (pesos)	SWM Expenses(t) = SWM Expenses(t - dt) + (MRCF expenses + IEC expenses + transport expenses) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	SWM Fund	Stock	The current amount available for SWM items (pesos)	SWM Fund(t) = SWM Fund(t - dt) + (SWM budget inflow + daily income from waste diversion - to MRCF fund - to IEC fund - to transport equipment fund - to government incentives fund) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	Transport Equipment Fund	Stock	The current amount available for funding transport equipment(pesos)	Transport Equipment Fund(t) = Transport Equipment Fund(t - dt) + (to transport equipment fund - transport expenses) * dt	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	daily income from waste diversion	Flow	The profit gained daily from selling produced compost and recyclables (pesos)	(daily sale from composting-CF DAILY OPERATING EXPENSE)+(daily sale from recycling-RF DAILY OPERATING EXPENSE)	Magalang (2014); Guerrero *et al.* (2013)	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
SWM Budget	IEC expenses	Flow	Daily expenses for information education and communication campaigns (pesos/day)	IEC Fund	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	MRCF expenses	Flow	Daily expenses for operating the MRCF (pesos/day)	CF expenses+RF expenses	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	SWM budget inflow	Flow	The annual inflow of money from the City Budget into the SWM Budget (pesos/yr)	SWM budget inflow = PULSE((SWM BUDGET ALLOCATION/100)*City Budget,(365),(365))	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	to IEC fund	Flow	Daily flow of money into funding for information education and communication campaigns (pesos/day)	SWM Fund*(ALLOCATION FOR IEC/100)	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	to MRCF fund	Flow	Daily flow of money into funding for the MRCF(pesos/day)	SWM Fund*(ALLOCATION FOR MRCF/100)	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	to transport equipment fund	Flow	Daily flow of money into funding for transport equipment (pesos/day)	SWM Fund*(ALLOCATION FOR TRANSPORT EQUIPMENT/100)	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	transport expenses	Flow	Daily expenses for funding transport equipment (pesos/day)	(daily actual cost of collection+daily actual cost of disposal)+((daily actual cost of collection+daily actual cost of disposal)*(TE MOOE FRACTION/100))	Magalang (2014); Guerrero *et al.* (2013)	N/A
SWM Budget	yearly budget inflow	Flow	The annual inflow of money into the City Budget (pesos/yr)	yearly budget inflow = PULSE(BUDGET CONSTANT,365,365)	Magalang (2014); Guerrero *et al.* (2013)	City Government of Malolos 2015 Budget
SWM Budget	ALLOCATION FOR IEC	Converter	The fraction of the solid waste management budget allocated for information education and communication campaigns (unitless)	Constant value	Magalang (2014); Guerrero *et al.* (2013)	Authors' judgement based on City Government of Malolos 2015 Budget
SWM Budget	ALLOCATION FOR MRCF	Converter	The fraction of the solid waste management budget allocated for the material recovery and composting facility (unitless)	Constant value	Magalang (2014); Guerrero *et al.* (2013)	Authors' judgement based on City Government of Malolos 2015 Budget
SWM Budget	ALLOCATION FOR TRANSPORT EQUIPMENT	Converter	The fraction of the solid waste management budget allocated for transport equipment (unitless)	Constant value	Magalang (2014); Guerrero *et al.* (2013)	Authors' judgement based on City Government of Malolos 2015 Budget
SWM Budget	BUDGET CONSTANT	Converter	The amount of money that enters the city budget annually (pesos)	Constant value	Magalang (2014); Guerrero *et al.* (2013)	City Government of Malolos 2015 Budget
SWM Budget	COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE	Converter	The cost of collection and disposal per ton of solid waste in the city (pesos)	Constant value	Paul *et al.* (2008)	City Government of Malolos, Personal interview
SWM Budget	daily actual cost of collection	Converter	The actual cost of collecting waste daily (pesos)	(city waste collection)*(COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE*percent of cost for collection)+(separation of special waste)*(COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE*percent of cost for collection)	Paul *et al.* (2008)	N/A

Appendix II. Model variables.

Sector	Name	Type of Element	Description (Units)	Value of Equation	Supporting Reference	Data Source
SWM Budget	daily actual cost of disposal	Converter	The actual cost of disposing waste daily (pesos)	(daily city waste disposal*(COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE*percent of cost for disposal))+(unprocessed waste from MRCF*(COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE*percent of cost for disposal))+(direct disposal of special waste*(COST OF COLLECTION AND DISPOSAL PER TON OF SOLID WASTE*percent of cost for disposal))	Paul *et al.* (2008)	N/A
SWM Budget	percent of cost for collection	Converter	The fraction of waste expenses that is spent for collection (unitless)	2/3	Paul *et al.* (2008)	Paul *et al.* (2008)
SWM Budget	percent of cost for disposal	Converter	The fraction of waste expenses that is spent for collection (unitless)	1/3	Paul *et al.* (2008)	Paul *et al.* (2008)
SWM Budget	SWM BUDGET ALLOCATION	Converter	The fraction of City Budget that is allocated for SWM (unitless)	Constant value between 0 and 100.	City Government of Malolos 2015 Budget	City Government of Malolos 2015 Budget
SWM Budget	TE MOOE FRACTION	Converter	The fraction of additional cost for transport equipment towards maintenance and operation (unitless)	Constant value between 0 and 100.	Authors' judgement	Authors' judgement
Waste Composition Constants Sector	COMPOSTABLE FRACTION	Converter	Fraction of compostable material in solid waste (unitless)	Constant value between 0 and 100.	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Waste Composition Constants Sector	PAPER FRACTION	Converter	Fraction of paper material in solid waste (unitless)	Constant value between 0 and 1	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Waste Composition Constants Sector	PLASTIC FRACTION	Converter	Fraction of plastic material in solid waste (unitless)	Constant value between 0 and 1	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Waste Composition Constants Sector	RECYCLABLE FRACTION	Converter	Fraction of recyclable material in solid waste (unitless)	Constant value between 0 and 100.	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Waste Composition Constants Sector	RESIDUAL FRACTION	Converter	Fraction of residual material in solid waste (unitless)	Constant value between 0 and 100.	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)
Waste Composition Constants Sector	SPECIAL WASTE FRACTION	Converter	Fraction of special waste material in solid waste (unitless)	Constant value between 0 and 100.	City Government of Malolos WACS (2014)	City Government of Malolos WACS (2014)