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Research Paper

Composting system improvement by life cycle assessment approach on community composting of agricultural and agro industrial wastes

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Abstract
In order to improve a community composting system, three scenarios have set based on the critical points of initial system from sensitivity analysis result of Life Cycle Assessment of community composting system of agricultural and agro industrial wastes composting. Sensitivity analysis of initial system revealed two critical points that used as consideration on setting of improvement system scenarios. On initial system, composting process contributed the highest impact potency on acidification, eutrophication, global warming, and photochemical oxidation, while distribution was responsible for the highest impact on human toxicity potential. By comparison of initial composting system with three improvement scenarios, it found that the third improvement scenario (SC3) was the best scenario that recommended to be implemented. SC3 promoted application of compost blanket for gases emission reduction of compost pile, and substitution diesel fuel of pick-up with CNG fuel for transportation emission reduction. This scenario reduced impact of initial composting system by 29% with the highest impact reduction was on global warming potential by 54%.

Keywords
life cycle assessment, composting system, agricultural and agro industrial wastes, sensitivity analysis, improvement scenarios

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1. INTRODUCTION

Composting has been applied as basic method to treat, minimize, and utilize organic wastes that produced by municipality, agricultural and agro industrial activity, because of its simplicity and cheapness. It produces compost which is safe and beneficial to apply for land and more environmentally friendly than chemical fertilizer (Andersen et al., 2012).

In Thailand, application of composting has been introduced to the communities in order to increase their participation on providing organic compost for their own needs, as well as to improve their income through composting plant development program (Siriwong et al., 2009; Aziz et al., 2012). Composting plant treats animal manures as the main material for composting such as cow dung, chicken, swine, duck and bat manures, besides palm oil mill waste, rice mill, and rubber wood manufacturing wastes (Chevakidagarn et al., 2013). Operation of these composting plants can reduce waste generation of agricultural and agro industrial activities such as rice plantation, sugarcane, corn, cassava, oil palm, rubber, soybean, mug bean and peanut bean (DEDE, 2012), and from animal farming such as cow manures, buffalo, chicken, pig and duck farming on provinces of Nakhon Si Thamarat, Phatthalung, Surat Thani, and Songkhla (Sridang et al., 2013). Performance evaluation of community composting plants in Southern Thailand revealed that composting plant was facing problem on low efficiency of composting technique, and improvement of composting technology was recommended to be done (Siriwong et al., 2013)

Application of Life Cycle Assessment (LCA) has been introduced in last decade due to assessing impact of composting system on the environment (Komilis and Ham, 2004; Cadena et al., 2009; Andersen et al., 2010; Colón et al., 2010; Martínez-Blanco et al., 2010; Rigamonti et al., 2010). The studies investigated various composting methods such as windrows, tunnels, static pile, and composter. Previous studies was concerned on organic fraction of municipal solid wastes as pruning waste, yard waste, organic household waste, garden waste, and left over raw fruits and vegetables. It concluded that composting process impacted the environment through global warming, acidification, photochemical oxidation, eutrophication, ozone depletion and human toxicity impacts (Andersen et al., 2012; Cadena et al., 2009; Martínez-Blanco et al., 2010).

LCA has also been applied in comparing composting method due to system improvement (Lundie and Peters, 2005; Liamsanguan and Gheewala, 2008; Martínez-Blanco et al., 2009; van Haaren et al., 2010; Boldrin et al., 2011; Aziz and Chevakidagarn, 2016). In comparing composting systems some improvements that recommended such as improvement of purities of being composted wastes and reduction of gaseous emission by gas treatment (Cadena et al., 2009), transportation distance arrangement (Martínez-Blanco et al., 2010), and fuel fossil substitution (Andersen et al., 2010).

In order to study the composting technique that practiced on community composting and its impact to the environment, LCA study was done on community composting of agricultural and agro industrial waste. By considering some improvements that recommended by Aziz and Chevakidagarn (2016), this study aims to find the better improvement scenario in order to improve the initial composting system of agricultural and agro industrial wastes.

2. EXPERIMENTAL SECTION

2.1 Investigated Composting System

Studied composting plant is located on Rattaphum District in Songkhla Province, Southern part of Thailand. Composting system consisted of feedstock collection, composting process which included electricity consumption and transfer material onsite plant, and distribution of compost product to customer. On composting process, agricultural and agro industrial wastes (AWW) is mixed with phosphate rock and bio-activator mixture before being fermented for 20 days. AWW contains with agricultural wastes which consists of goat manure, chicken manure, and bat manure, and agro industrial wastes consists of rice husk, rice bran, and decanter cake. Bio-activator mixture is made up with molasses, liquid fertilizer, and seed from government to produce powder compost.

Composting process applies static pile method with intermittent aeration, with no leachate produced and no air emission reduction technology applied. Compost products quality has been certified and could be applied for fruit farming and oil palm and rubber plantation. Figure 1 configured diagram of related phases in the composting systems.

2.2 Life Cycle Assessment

LCA defines as a method to assess the impacts of a product, process or service throughout the product's life cycle into the environment that includes from raw materials acquisition to disposal of the product at the end of its life (UNEP/SETAC, 2009). LCA has four phases; goal and scope definition; inventory analysis; impact assessment; and interpretation. Analysis of environmental impacts of initial composting system and scenarios of system improvements was performed by software SimaPro v.7.3.0 (PRe-Consultants, 2012).

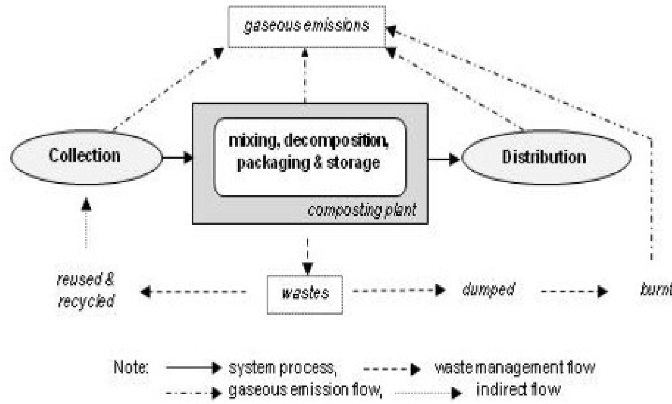

Figure 1. Flowchart of studied composting system

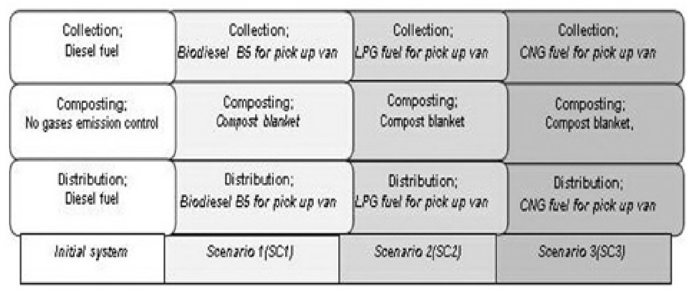

Figure 2. Comparison of Composting System Scenarios

In the first step, goal and scope were defined. Goal of this study is to find a better composting system by comparing initial composting system that composted agricultural and agro industrial wastes with other improvement scenarios. The study scoped on comparing initial composting system that produced powder compost and three improvement scenarios based on reduction of composting gaseous emission, and substitution of fossil fuel to alternative fuels consists of biodiesel 5% (B5), Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG). The functional unit (FU) is management of 1 ton of AAW to gain compost.

System boundary of the study includes of collection of feedstock, composting process and distribution of compost to customers. Otherwise, impact of material handling, fabrication of transportation vehicles, composting station, and related equipment were out of concern of this study due to the impacts were not related directly to the operation of composting system. Allocation procedure is related to production process of composting that treated base on mass of compost produced, environmental burden of waste only related to dumped waste referred to cut-off method (Ekvall et al., 1998).

On the second step, inventory analysis, data of initial system were collected from related study by Aziz and Chevakidagarn (2016). Meanwhile, data for improvement scenarios were collected from references related to application of compost blanket as gaseous emission reduction (CIWMB, 2007; Utami et al.,

Table 1. Inventory of Initial Composting System

Phases	Items	Volume	Unit
Input			
Collection	truck and pick up van	64.08	tkm
Composting			
- feedstock	AAW	1,000.00	kg
	phosphate rock	142.39	kg
	bio-activator mixture	6.98	kg
- water consumption	water	98.38	kg
- electricity	mixer, conveyor, blower, crusher, sewing machine	5.72	kWh
- transfer material	mini tractor	0.18	tkm
Distribution	truck and pick up van	148.05	tkm
Output			
Gaseous emissions	CH4	0.49	kg
	NH3	1.54	kg
	N20	0.15	kg
Compost product	compost	987.03	kg
	packaging	4.01	kg
Waste	total	4.92	kg
- dumped	plastic (bag, rope, packaging)	0.66	kg
- reused	plastic (bag, rope)	4.24	kg
- recycled	Cardboard	0.02	kg

Source: [19]

Table 2. Impact Characterization Result of Initial System

Impact	Unit/FU	Total	C	Co	D
AP	kg SO_2 eq.	2.643	0.063	2.471	0.109
	%	100	2.400	93.470	4.130
EP	kg $PO_4{}^{-3}$ eq.	0.582	0.015	0.541	0.026
	%	100	2.640	92.820	4.540
GWP	kg CO_2 eq.	102.740	16.642	57.501	28.597
	%	100	16.200	55.970	27.830
HTP	kg 1,4-DB eq.	0.557	0.144	0.165	0.248
	%	100	25.890	29.620	44.490
POP	kg C_2H_4	0.005	0.001	0.003	0.001
	%	100	15.590	57.620	26.790

Note: C: collection, Co: composting, D: distribution

2012), and gaseous emission from biodiesel B5, LPG and CNG consumption on transportation (TGO, 2013).

Impact assessment as the third step was conducted by using the CML 2 baseline 2000 method that developed by Centre of Environmental Science of Leiden University (Martínez-Blanco et al., 2010). Impact categories considered categories that have selected on related studies (Cadena et al., 2009; Martínez-Blanco et al., 2010) which included abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP), human toxicity potential (HTP), and photochemical oxidation potential (POP).

Finally on interpretation step, the interpretation of initial system was followed by sensitivity analysis. It was done to find critical points to be considered as system improvement spots. All improvement scenarios then were compared in order to find the best scenario to be applied for system improvement. The best scenario was the scenario that has higher impacts reduction in comparison with initial system and more applicable with less consequences of economic and technology impact. Moreover, the best scenario was compared with initial composting system to observe detail impact reduction that occurred.

Table 3. Sensitivity Analysis Scenarios

Impact category	initial (%)	Sensitivity analysis scenarios (%)				
		SA1	SA2	SA3	SA4	SA5
AP	100	100	77	53	99.7	100
EP	100	100	77	54	100	100
GWP	100	100	87	75	99.98	93
HTP	100	99.997	93	86	99.9	100
POP	100	99.999	86	72	94	100
Impact category	**initial (%)**	**Sensitivity analysis scenarios (%)**				
		SA6	SA7	SA8	SA9	SA10
AP	100	100	100	100	99	98
EP	100	100	100	100	99	98
GWP	100	86	99.98	99.97	100	100
HTP	100	100	100	100	89	79
POP	100	100	95	90	100	100
Impact category	**initial (%)**	**Sensitivity analysis scenarios (%)**				
		SA11	SA12	SA13	SA14	
AP	100	99.89	99.89	99.999	99.997	
EP	100	99.9	99.9	99.998	99.997	
GWP	100	98	98	99.99	99.98	
HTP	100	99.1	99.1	99.99	99.97	
POP	100	99	99	99.99	99.98	

3. RESULTS AND DISCUSSION

3.1 Initial Composting System

On initial system, data collected on inventory analysis showed in Table 1. It depicted that in providing feedstock of 1 ton to be composted AAW took 64.26 tkm on collection phase. Composting process input were 1 ton AAW, 142.39 kg phosphate rock, 6.98 kg bio-activator mixture (consisted of molasses, fluid bio fertilizer, and seeds), consumed 98.38 kg water, 5.72 kWh electricity for machineries, and 0.18 tkm on transferring material onsite plant. On distributing compost to customers 148.05 tkm was needed. Meanwhile composting process emitted gaseous consisted of methane, dinitrogen monoxide, and ammonia. Composting process was also generated wastes which later recycled, reused, and the rest were dumped and burnt.

Data inventory of initial system were classified and characterized for environmental impact assessment. CML 2 baseline 2000 method was used, and no discussion was performed about ADP and ODP impact categories due to no impact from present study on these categories. Impact on environmental of each steps of initial composting system was summarized in Table 2.

It can be seen that higher sensitivity was shown on the change of gaseous emission quantity from composting process and transportation activities. Reduction of gaseous emission (SA2 and SA3) were significantly reduced environmental impacts on AP, EP, GWP, HTP and POP which exceeded 47%, 46%, 25%, 14% and 28%, respectively by 50% emission reduction. Meanwhile, on gaseous emission reduction on transportation activities (SA4 to SA10) reduction all emission of CH_4 and SO_2 (SA4) only reduce 6% of impact of POP, 0.3% of AP, and 0.1% of HTP. Reduction of CO_2 (SA5 and SA6) and CO (SA7 and SA8) emission by 50% could reduce impact on GWP and POP by 14% and 10%, respectively, while reduction of N_2O emission (SA9 and SA10) by 50% could reduce impact on HTP by 21%.

Otherwise, sensitivity analysis (SA11 to SA14) shows that efficiency on electricity consumption (SA11 and SA12) by 50% were not sensitively reduced environmental impact, similar condition concluded from reduction of transfer material distance onsite plant (SA13 and SA14). It revealed that improvement of composting system could be performed by application of gaseous emission reduction from composting process and transportation activities.

3.2 Improvement Analysis

Based on sensitivity analysis result, improvement scenarios were developed in order to find the better system, three scenarios were introduced with improvement options by considering: a) better operation on composting gaseous emission reduction by choosing the application of compost blanket on the surface area of composting pile, refers to Utami et al. (2012) and CIWMB (2007), this application could reduce emission of methane and dinitrogen monoxide up to 70% and 75%, respectively; and b) reduction of gaseous emission from transportation by shifting types of fuel consumed, based on emission factor that issued by TGO (2013), three alternatives of fuels including biodiesel B5, LPG and CNG were selected as pick up van fuel with consideration of com-

Table 4. Impact Characterization of Improvement Scenarios System

Impact	Unit/FU	Initial	SC1	SC2	SC3
AP	kg SO_2 eq.	2.643	2.643	2.557	2.56
EP	kg PO_4^{-3} eq.	0.582	0.582	0.562	0.562
GWP	kg CO_2 eq.	102.74	62.286	47.256	47.121
HTP	kg 1,4-DB eq.	0.557	0.559	0.366	0.371
POP	kg C_2H_4	0.005	0.003	0.007	0.002

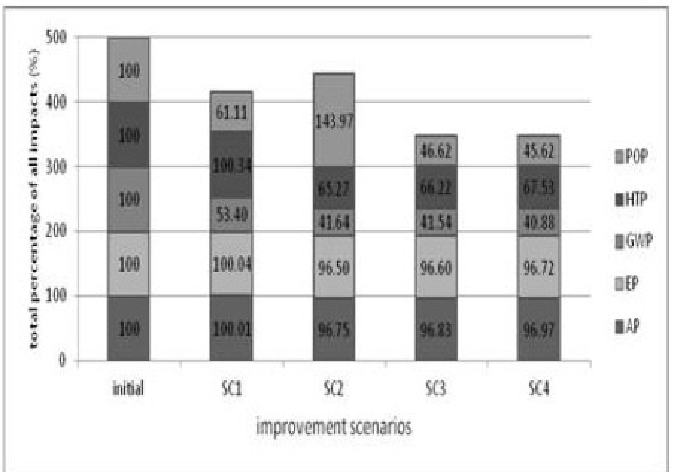

Figure 3. Impact Comparison of Initial System and Improvement Scenarios

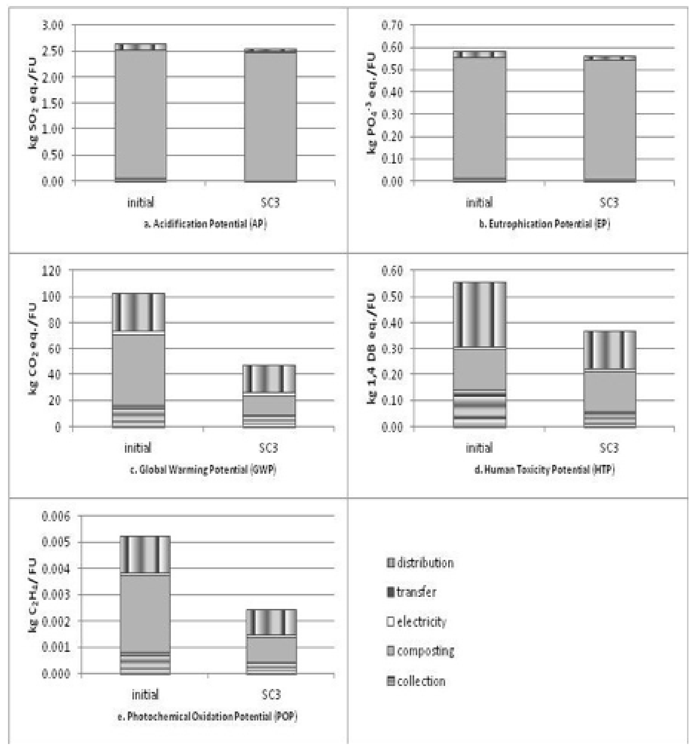

Figure 4. Impact Comparison of Initial and SC3 Composting System

mercially provision of fuel. Comparison of initial system and improvement scenarios was shown on Figure 2.

First scenario (SC1) considered application of compost blanket; and shifting of fuel of pick-up van on collection and distribution by using biodiesel B5, and pick-up truck use diesel. Scenario 2 (SC2) applied improvement through shifting of fuel of pick-up van as collection and distribution vehicle with LPG. And scenario 3 (SC3) applied shifting of fuel of pick-up van into CNG fuel.

Comparison of impact of initial and improvement scenarios showed on Table 4 and Figure 3. Table 4 and Figure 3 revealed that all improvement scenarios were contributed lower impact than initial system, except for impact category AP, EP and HTP on SC1 and POP category on SC2. Higher impact on category of AP, EP and HTP were attributed by consumption of biodiesel B5 that emitted more NO2 to the environment than diesel. Higher impact on POP category was contributed by emission of CO of LPG fuel that higher than diesel fuel. SC3 showed impact reduction on all impact categories with the higher impact reduction was performed on GWP by 54% of initial impact. By comparing percentage of total impact reduction on Figure 3, it could be concluded that SC3 was the best scenario of improvement.

Table 5 and Figure 4 represented impact characterization results of SC3. In SC3 all sub systems were contributed to all impact categories, similar with initial composting system. Composting process was responsible for the highest contribution to all impact categories, except for POP which was supplied by distribution sub system. Composting process was contributed 2.464 kg SO_2 eq./FU (96.26%), 0.539 kg PO_4^{-3} eq./FU (95.87%) and 0.154 kg 1,4-DB eq./FU (41.52%) of total impact on AP, EP and HTP, respectively. Distribution sub system was responsible for contribution of 19.815 kg CO_2 eq./FU (42.05%) and 0.001 kg C2H4/ FU (40.48%) of total impact on POP.

In detail, in comparison with initial composting system (see Table 2, Table 5 and Figure 4), it can be observed that all impacts reduction was occurred in all impact categories. Impact reduction were contributed by collection, electricity and distribution sub systems in all impact categories, while composting process sub system was attributed impact reduction only on GWP and POP categories, and for other impact categories were similar with initial composting system as well as transfer sub system since no improvement option applied on it.

Table 5. Impact Characterization Result of SC3

Impact	Unit	Total	C	Co	D
AP	kg SO_2 eq.	2.55	0.025	2.471	0.064
	(%)	-100	-0.99	-96.51	-2.51
EP	kg $PO_4{}^{-3}$ eq.	0.562	0.006	0.54	0.016
	(%)	-100	-1.12	-96.08	-2.8
GWP	kg CO_2 eq.	47.121	9.164	18.142	19.815
	(%)	-100	-19.45	-38.5	-42.05
HTP	kg 1,4-DB eq.	0.371	0.059	0.165	0.147
	(%)	-100	-15.83	-44.45	-39.72
POP	kg C_2H_4	0.002	0.0004	0.0008	0.0008
	(%)	-100	-18.03	-41.49	-40.48

Note: C: collection, Co: composting, D: distribution

4. CONCLUSIONS

Life cycle assessment in addition to useful on addressing environmental impact can also be useful for assessing improvement scenario of a system. Studied community composting system of agricultural and agro industrial wastes could be improved by applying compost blanket and substitution of transportation fuel from diesel to CNG. The best improvement system was SC3 that could reduce impact by 29% of total impact percentage of initial composting system with reduction of impact on GWP by 54%.

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