Journal of Sustainability Science and Management
Volume 11 *Number* 2, December 2016: 57-69
ISSN: 1823-8556

LIFE CYCLE SUSTAINABILITY ASSESSMENT OF COMMUNITY COMPOSTING OF AGRICULTURAL AND AGRO INDUSTRIAL WASTES

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Abstract: This study applied simplified Life Cycle Sustainability Assessment (LCSA), a comprehensive sustainability assessment of a products or processes along their whole life cycle, to assess sustainability performance of community composting system that treated agricultural and agro industrial wastes to produce compost in powder and granular form. Impact assessment of the powder compost system (PCS) showed that it impacted environment at 1.9E-11 point, economic at 7,238.75 THB (Thai Baht), and social at 3.33 scoring units, while the granular compost system (GCS) impacted the environment, economic and social aspects at 2.1E-11 point, 9,383.35 THB, and 3.50 scoring units, respectively. Comparison of PCS and GCS showed that GCS impacted 1.1, 1.3 and 1.1 times higher than PCS on environment, economic, and social aspects, respectively. LCSA evaluation revealed that GCS was 1.00001 times more sustainable than PCS. Improvement of compost systems through application of compost blanket and substitution of fuel on both systems could reduce the impact on the environment, increase economic benefits while there would be no changes on social impact, and furthermore it could increase the sustainability of composting systems.

Keywords: Life cycle sustainability assessment, sustainable performance, community composting, agricultural and agro industrial wastes.

Introduction

In recent years the worldwide paradigm in dealing with environmental impacts has shifted from environmentally friendly products to sustainable products (Zamagni, 2012). Products are not only assessed on their environmental aspects but also on economic and social characteristics, as the three pillars of sustainability. The shifting of this paradigm has driven the development of Life Cycle Sustainability Assessment (LCSA) due to the need of evaluation methods and tools for environmental and sustainability performance (Finkbeiner *et al.*, 2010). LCSA evaluates all negative impacts and benefits on environmental, social and economic aspects toward more sustainable products throughout their life cycle in order to use in decision making processes (UNEP/SETAC, 2011).

LCSA can be performed by combining three life cycle based tools, namely environmental life cycle assessment (LCA), life cycle costing (LCC), and social life cycle assessment (S-LCA) with consistency of system boundaries, or can be performed as the new LCA by added with economics and social impact assessment besides environmental impacts (Kloepffer, 2008). LCSA consists of four main steps including goals and scope, inventory, impact assessment, and interpretation, with consistent system boundaries on LCA, LCC and S-LCA (UNEP/SETAC, 2011).

As a new developing tool, few research publications are available about LCSA application. Although the LCSA framework has issued by UNEP/SETAC (2011) and some studies referred to sustainable assessment framework, there were fewer studies that used LCSA terminology. The studies were on various topics including assessment of the sustainability of fuels (Zhou *et al.*, 2007), assessment of marble products performance in Italy (Traverso *et al.*, 2012), examining the sustainability aspects of different strategies for the treatment of waste in China (Lu, 2009), mangrove management strategies in Thailand (Moriizumi *et al.*, 2010), assessment of sustainable solid waste management in Thailand (Menikpura *et al.*, 2012) and assessing the sustainability of disposal methods of polyethylene terephthalate (PET) bottles in Mauritius (Foolmaun & Ramjeawon, 2013).

In conducting LCSA, several methods were applied especially covering the period before the LCSA framework was issued. Some studies proposed their own method which still consists of analysis of the three pillars of sustainability, while others used the framework of sustainability assessment, based on sustainability indicator definitions, continued with assessing the indicators on life cycle steps, and finally, some options were compared to find the more sustainable scenarios/ options of a system (Zhou *et al.*, 2007; Moriizumi *et al.*, 2010).

Meanwhile, Menikpura *et al.* (2012) introduced another method known as broaden and deepen LCA to perform LCSA. This refers to an additional pillar of economic and social analysis, and an additional method of impact measurement. Moreover, composite indicators were used for environmental, economic, and social sustainability. It consists of damage to ecosystem and damage to abiotic resources as environmental sustainability; life cycle cost as economic sustainability; and damage to human health and community well-being as social sustainability.

Furthermore, other studies applied similar approaches as the LCSA framework of UNEP/ SETAC (2011) with terms of LCA, LCC and S-LCA (Traverso *et al.*, 2012; Lu, 2009; Foolmaun & Ramjeawon, 2013). Foolmaun and Ramjeawon (2013) developed a method which refers to the LCSA framework and introduced options for evaluating LCSA in order to support decision making by applying Analytical Hierarchy Process (AHP).

In contrast, as a part of LCSA, among other tools, LCA has been applied in many fields of study including composting. It was triggered by consideration of gaseous emissions of the composting process that potentially impacts the environment. In past decades, many studies reported gaseous emissions from various composting methods that have been considered harmful to the environment, including windrows, tunnels, static piles, and composters. These studies were conducted in homes and industrial composting, and treated many kinds of composting raw materials such as the organic fraction of municipal solid waste, pruning waste, yard waste, organic household waste, garden waste, and left over raw fruits and vegetables. (Komilis & Ham, 2004; Cadena *et al.*, 2009; Martinez-Blanco *et al.*, 2010; Colon *et al.*, 2010; Andersen *et al.*, 2010).

By application of LCA on composting systems, it was reported how the contribution of composting processes impacted on global warming, acidification, photochemical oxidation, eutrophication, ozone depletion and human toxicity (Cadena *et al.*, 2009; Martinez-Blanco *et al.*, 2010; Andersen *et al.*, 2012). Moreover, in order to broaden the scope of the system, impacts from transportation, composter production, and manufacturing should be considered (Martinez-Blanco *et al.*, 2010). In addition, LCA application was used on composting system comparisons as a part of solid waste management option with other methods (Lundie & Peters, 2005; Liamsanguan & Gheewala, 2008; Martinez-Blanco *et al.*, 2009; van Haaren *et al.*, 2010; Boldrin *et al.*, 2011) and the comparisons of two composting systems applying different technology (Cadena *et al.*, 2009; Martinez-Blanco *et al.*, 2010; Andersen *et al.*, 2012). Through system comparisons, it was found that some improvement options were recommended including improving purities of waste to be composted and gases treatment to reduce gaseous emission (Cadena *et al.*, 2009), arranging collection and transportation distance (Martinez-Blanco *et al.*, 2010), and substitution of energy with fuel fossil sources-based (Andersen *et al.*, 2012).

As a part of sustainable agriculture practice and self-sufficiency economy program, the Thai government has promoted the program one district one composting plant since 2002 by providing communities with composting plants, which aimed to develop community participation and finance by producing compost (organic fertilizer) that was more environmentally friendly for soil than chemical fertilizers (Siriwong *et al.*, 2009). Investigation of 36 community composting plants in Southern Thailand found that basic problems of composting plants were low efficiency of the composting technique, lack of raw materials supply, low quality of product, lack of labor, and inefficiency of marketing (Siriwong *et al.*, 2013). These problems related to three pillars of sustainability. In order to support sustainable agriculture through organic fertilizer provision, the composting system must be improved and become a sustainable composting system that gives less negative impact and more positive impacts on the environment as well as on economic and social aspects.

A preliminary study on four community composting plants in Southern Thailand has emphasized the results of previous investigations. This study is important due to the assessment of sustainability performance of community composting systems in order to support the sustainable agriculture in Thailand, as well as to give recommendations on system improvements in order to be sustainable community composting.

Materials and Methods

Composting Systems

Studied composting systems were based on operation of a community composting plant that produces powder and granular composts and is located in Rattaphum District, Songkhla Province, Southern Thailand. The composting system consists of the collection of raw materials, a composting process which includes electricity consumption and transfer of materials in plant site, and distribution of compost product to customers. Main raw materials are agricultural and agro industrial wastes (AAW) consisting of goat manure,

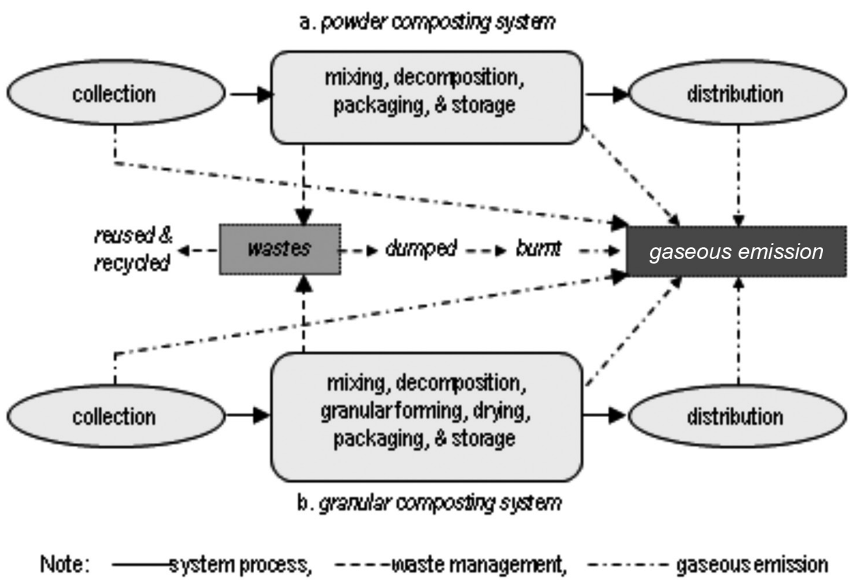

Figure 1: Flowchart of studied composting system

chicken manure, bat manure, rice husk, rice bran, and palm oil mill decanter cake. During the composting process, AAW were mixed with phosphate rock and bio-activator mixture before being fermented for 20 days. Powder compost is the product of 20 days fermentation, while granular compost is a 24 day process and is the product of powder compost that undergoes granular forming and is dried for 4 days. The composting process runs in static pile method with intermittent aeration. Compost products quality is certified and can be applied to oil palm and rubber plantations, and to fruit farm. Figure 1 presents a flowchart of related phases in the composting systems.

LCSA Methodology

Application of LCSA was based on a combination of LCA application for environmental aspects, LCC for economic aspects and S-LCA for social aspects of community composting system on a similar system boundary. LCSA consisted of four phases including goal and scope definition, data inventory, impact assessment, and interpretation.

LCSA Goal and scope definition

Goals and scope were defined by considering objectives and benefits of the study. This step was followed by determination of system boundaries and the functional unit. The functional unit of the composting process was one ton of waste that was treated during the process, referred to the study by Cadena *et al.* (2009). The final step, allocation procedure was done based on proportions of mass loads, costing and employment involved in the treatment of AAW to become the compost products.

LCSA inventory analysis

In this step, all data related to the composting system were collected. These were classified into primary and secondary data which were later used as LCA, LCC, and S-LCA data. Primary data were gained from field observation, laboratory analysis results, and interviews, while secondary data were obtained from plant report and related literatures.

LCA work was performed by SimaPro software 7.3.3 version (PRe Consultants, 2012). In this study new data were input on the software with slight modification by considering some assumptions including data on emission factors of transportation in Thailand, based on the Thai National Database (TGO, 2013) and a study by Nilrit and Sampanpanish (2012). In addition, data of percentages of electricity generation sources of Thailand were also used, based on the master plan of the Electricity Generation Authority of Thailand (EGAT, 2012).

LCSA impact assessment

For LCA, impact assessment was performed using two methods that have been applied by the related study of LCA on composting systems. The methods were CML (Centrum Milieukunde Leinden) 2 baseline 2000 that was developed by the Center of Environmental Science of Leiden University, the Netherlands, and EDIP (Environmental Design of Industrial Products) 2003 which was developed by the Danish Environmental Protection Agency, Denmark (PRe Consultants, 2012). Impact assessment consisted of two main steps including classification and characterization, and optional steps such as normalization, weighting, and single score determination. CML 2 baseline 2000 method was applied in the classification and characterization step, while EDIP 2003 was used on determining the normalization factor to perform a single score on the optional step since no single score method provided by CML 2 baseline 2000 method. The impact classifications that were used in this study were acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP) and photochemical oxidation potential (POP). Meanwhile, the characterization step was done by multiplying the amount of impact parameter by the characterization factors of related impacts that were already provided by the method developer. The optional step that was used in this study was single score. Single score was determined by normalization of the characterized impact, and was weighted into the certain score. The total score was the single score of the impacts.

Meanwhile in LCC, all collected data in the economics category on data inventory were classified into cost categories such as labor costs and material costs which included transportation, energy, maintenance costs. The characterization step was done by aggregation of the cost for the whole category.

Finally, in S-LCA, data inventory were classified into subcategories of child labor, fair salary, working hours, forced labor, health and safety, community engagement, local employment, and contribution to economic development. Characterization of S-LCA was done by weighting method, referring to the method that applied by Foolmaun and Ramjeawon (2013). Weighting score was classified based on criteria of best, better, good, and worst performance with score levels from 1 to 4 on a parameter of percentage of practices on the system.

LCSA interpretation

Interpretation for all aspects (LCA, LCC, and SLCA) was based on the comparison of characterization step results based on impact categories for entire life cycles of composting systems. Interpretation was done by contribution analysis in order to calculate the overall contribution to the results of the various factors. The contributions were usually expressed as percentages of the total.

LCSA evaluation

Due to decision making on more sustainable system, evaluation of LCSA was done by sustainability scoring method. LCSA evaluation was conducted by normalizing important impacts on environment, economic, and social aspects. The environmental aspect was represented by global warming potential (GWP) which was selected based on the current worldwide attention on environmental impacts of global warming which are indicated by CO_2 equivalent emission through policy of low carbon economies, low carbon products, etc. Moreover, GWP impact is one of the main contributors for total impact on environment from the composting process. In addition, reference data for other environmental impact categories of Thai conditions were not available. The economic aspect was represented by the profits of composting systems with consideration that profit would ensure sustainable business and its allocation would affect social development. Finally, the social aspect was represented by the number of those employed with consideration of workers that were directly impacted by the operation of composting plant to improve their living standards.

Normalization on environmental aspects was done by dividing the impact of global warming potential by the number of CO_2 equivalent emissions of the system with total number of CO_2 equivalent of Thailand reference on one year. Meanwhile, normalization on the economic aspect was done by dividing profit cost of composting system by Thailand's GDP (Gross Domestic Product) for one year. Finally, for the social aspect normalization was conducted by dividing the number of jobs created by the system with the total Thai population in the age of independency in a year. Results of all normalization steps were in no unit number.

The sustainability score of a system was calculated by the sum of important impacts of the system in correlation with levels of importance of sustainability aspects based on Thailand's governmental policy on National Sustainable Development Strategy (UNEP, 2008). Since global warming potential was a negative impact, so, the sustainability score was gained by the addition of (-) environmental score with economic and social scores. Environmental, economic, and social scores were the results of normalization results multiplied by the level of importance of sustainability. The more sustainable system was shown by higher sustainability scores.

Results and Discussion

Goal, Scope and System Boundary

Goals of this study were to assess the sustainability performance of composting systems for two types of compost product shapes through investigation on impacts of the composting process on the environment, and economically, and socially, and recommended improvement options. This study was conducted by scoping on main raw materials of compost from agricultural and agro industrial waste (AAW) which consisted of palm oil mill, rice mill, and animal farming wastes, and the study of their impact on the environment, economy, and society were limited to composting systems that consisted of raw materials collection, composting process and the distribution of the compost product to consumers.

System boundaries of this present study consisted of the collection of raw and supporting materials, the composting process including electricity consumption and transfer material vehicle usage, and finally the distribution of compost to customers. Impacts of composting systems related to the operation of the composting process, electricity consumption, and transportation activities, materials, costing and workers on construction, manufacturing of buildings, machines and other equipment were not of concern because they did not contribute direct impacts on the composting process. The system boundaries of this study are shown in Figure 2.

Powder and Granular Compost Systems

Data inventory of the powder compost system (PCS) and of the granular compost system (GCS) are shown in Table 1.

Table 1 presents the amount of materials and energy consumption, transportation needed and emission into environment on treating 1 ton of AAW to become powder and granular composts. Materials used included AAW, phosphate rock, bio activator mixture, water, and packaging that was utilized during treatment. Energy consumed came from electricity. Transportation activity included of collection of raw materials, transfer of material in plant site, and distribution of the product to customers. Gaseous emission

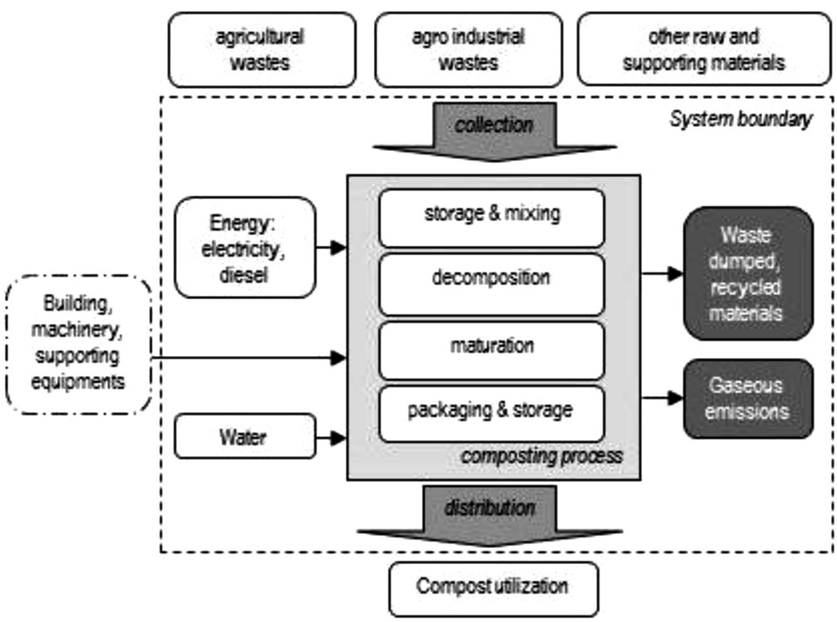

Figure 2: System boundaries of LCSA

Table 1: LCSA inventory of PCS and GCS

Items	**Unit/FU**	**PCS**	**GCS**
LCA			
Collection	ton-km	64.08	64.11
Composting process			
AAW	kg	1,000.00	1,000.00
phosphate rock	kg	142.39	142.39
bio activator mixture	kg	6.98	7.90
water	kg	98.38	111.33
electricity	kWh	5.72	11.80
transfer material	ton-km	0.16	0.37
gaseous emissions:			
- CO_2	kg	99.25	107.55
- CH_4	kg	0.49	0.69
- NH_3	kg	1.54*	1.67**
- N_2O	kg	0.15*	0.16**
compost product	kg	987.03	1,013.30
waste	kg	4.92	4.99
Distribution	ton-km	148.05	152.00
LCC			
Capital cost	THB	0.00	147.61
Operational cost	THB	3,894.87	3,944.87
Maintenance cost	THB	76.95	79.00
Wages cost	THB	2,309.63	3,891.08
Damage cost	THB	957.30	1,320.79
Total	THB	7,238.75	9,383.35
SLCA			
Child labor	person	0	0
Fair salary	person	6	6
Forced labor	person	0	0
Work accident	number	0	0
Health and safety awareness	person	6	6
Safety equipment	number	6	6
Local employment	person	70	70
Contribution to economic development	%	17.20	25.20

Source: *calculation based on assumption and several references, ** based on CO_2 increase percentage of granular compost from powder compost.
Note: THB = Thai Baht

into the environment consisted of CO_2, CH_4, NH_3 and N_2O. In addition, waste generation consisted of plastic and cardboard. Moreover, it explained costing components in which the total cost consisted of capital, operational, and maintenance costs, wages, and damage costs in treating 1 ton of AAW. Table 1 also explains about community involvement in compost production.

In comparing both systems, it can be observed that on LCA data, GCS consumed higher amounts of materials, energy, transportation activity, and costing than PCS, moreover GCS released higher amount of gas emissions, waste generation and contributed more on economic development. Higher materials, energy and transportation consumption and emission to the environment were attributed to the additional process to produce granular compost which needed more water and bio activator mixture and operation of more machinery such as a granular forming machine which consumed more electricity. Moreover, more gases were emitted due to additional fermentation and drying process for granular formation. Similar consequences related to waste generation of packaging materials used on additional process. Lastly, greater quantities of GCS produced meant more transportation activity was needed to distribute the compost product to customers.

By comparison with related studies on LCA by Martinez-Blanco *et al*. (2010) and Colon *et al.* (2010), in composting process, this study consumed lesser amounts of water and electricity than composting in industrial scale whilst more than composting in home scale. It could be occurred related to composting production rate and equipment used. Moreover, it was observed that concentrations of NH_3, CH_4 and N_2O released of this study were higher than in industrial and home composting. It could be happened because of the raw material composition of this study consisted higher portion of manure than green waste, whilst related studies only consisted of organic or green wastes. Furthermore, this study generated lesser amounts of waste than industrial and home composting. It was related the homogeneous raw materials used, thus, no pretreatment needed to reduce material size in order to ease the composting process, beside the waste management practices such as reusing and recycling on present study location. Meanwhile on total transportation activities this study, needed more value on mass-distance than industrial and home composting practices, which related to longer transportation distance of present study than related studies.

Meanwhile on LCC data, higher costing of GCS than PCS was related to the higher amounts of materials, as well as energy and transportation needed that contributed to higher operational and maintenance costs. More working hours for workers on the granular forming process contributed to higher wage costs, more gas emissions and waste generation contributed to higher damage costs. Furthermore, the higher price of granular compost gave more profit for the management and, therefore, it shared more profit as a contribution to the economic development of the community.

Impact of Powder and Granular Compost Systems

Impact characterizations of PCS and GCS are presented in Table 2.

PCS and GCS were responsible for environmental impacts of AP, EP, GWP, HTP, and POP with the domination portion in a single score being AP at 56%, EP at 30% and GWP at 14% of a single score which was mostly contributed by the composting process. Moreover, on costing, PCS was impacted at 7,238.75 THB with a higher portion of costing on material and operation cost at 68%, while GCS was impacted at 9,383.35 THB with higher portion of cost was on material and operational cost at 59%. Meanwhile, PCS was impacted socially at 3.33 scoring unit, while GCS was impacted at 3.50 scoring unit. The higher scoring unit of GCS compared with PCS was related to higher contribution to economic development which impacted 2 times than PCS.

In comparison to related studies on LCA, it was found that composting system was impacting the environment on AP, EP, GWP, HTP and POP categories, similar with studies of Cadena *et al.* (2009), Martinez-Blanco *et al.* (2010), and Andersen *et al.* (2012). Moreover, this study found that one of the main sources of environmental impact was gaseous emissions of the composting process, in line with related study of Cadena *et al.* (2009).

Table 2: LCSA impact assessment results of PCS and GCS

Impact Category	Unit/FU	PCS	GCS
LCA			
Acidification potential (AP)	kg SO_2 eq.	2.643	2.892
Eutrophication potential (EP)	kg PO_4^{-3} eq.	0.582	0.636
Global warming potential (GWP)	kg CO_2 eq.	102.740	113.980
Human toxicity potential (HTP)	kg 1,4-DB eq.	0.557	0.590
Photochemical oxidation potential (POP)	kg C_2H_4	0.005	0.007
Single score	Point	1.9E-11	2.1E-11
LCC			
Material and operation cost	THB	4,929.12	5,492.27
Labor cost	THB	2,309.63	3,891.08
Total	THB	7,238.75	9,383.35
SLCA			
Child labor	scoring unit	4	4
Fair salary	scoring unit	4	4
Forced labor	scoring unit	4	4
Health and safety	scoring unit	4	4
Local employment	scoring unit	3	3
Contribution to economic development	scoring unit	1	2
Average	scoring unit	3.33	3.50

In comparing both systems, it can be observed that GCS impacted environmental, economic and social aspects more than PCS. As described in the previous section, it was contributed to by an additional process for granular formation that emitted more greenhouse gases. It was followed by an increase in materials and operation, and labor costs that positively increased the management profits. Furthermore, the profits impacted the community positively through profit sharing for the economic development of the community.

Impact Comparison

Based on results of the impact assessment of LCA, LCC, and SLCA, comparisons of both systems are represented in Figure 3.

From Figure 3, it can be seen that GCS was impacted 1.1 times higher than PCS on environment, while on costing GCS contributed a higher impact at 1.3 times that of PCS, whilst GCS impacted society 1.1 times higher than PCS. Finally, it can be concluded that GCS gave a higher negative impact on the environmental

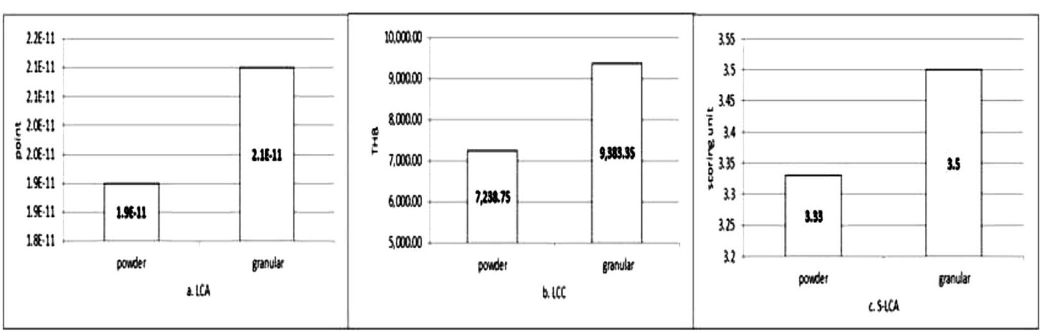

Figure 3: LCSA impact comparisons of PCS and GCS

aspect, but, conversely, gave higher positive impacts on economic and social aspects.

Sustainability Scoring

The sustainability score of a system was calculated by the sum of normalized important impacts of the system in correlation with the level of importance of sustainability aspects. Table 3 describes the normalization calculation of important impacts on the environment, economic aspects, and society represented by GWP, profits and local employment.

It can be seen in Table 3 that normalization of impacts of PCS were 2.39E-10, (1.18E-11), and 4.00E-07 on environment, economic and social aspects, respectively. Meanwhile, normalization of GCS impacts were 2.65E-10, 3.08E-11, and 4.00E-07 on environment, economic and social aspects, respectively.

The sustainability importance level of Thailand was referred to in the National Sustainable Development Strategy (UNEP, 2008) which described sustainable development strategies in Thailand as consisting of (1) elimination of poverty through sustained and equitable economic growth; (2) enhanced environmental security and sustainability; (3) creation of a knowledge-based society and ethical society; (4) assurance of good governance at all levels of society.

This strategy showed that the economic aspect had first priority, the environmental aspect the second, and the social aspect was the last. Although no exact percentage was introduced, with assumption of priority level of sustainable importance, it can be concluded that the percentage of the economic aspect was bigger than that of the environmental aspect, and that of the environmental aspect in turn was bigger than that of the social aspect. By this assumption, several models of levels of sustainable importance were investigated to find the best sustainability score, and the results were the best model for it was 37.5% for the economic aspect, 32.5% for the environmental aspect, and 30% for the social aspect. Sustainability scores of both compost systems are shown in Table 4.

Table 4 shows that in order to evaluate LCSA, the environmental impact was put as a negative impact, whilst others were positive impacts. By summing up all these impacts

Table 3: Normalization of impact characterization

Items	Impact			Thailand Reference (Unit/year)*		Normalization	
	PCS	GCS	Unit/FU			PCS	GCS
GWP	102.740	113.980	kg CO_2	295,282 x 10^6	kg CO_2 eq.	2.39E-10	2.65E-10
Profits	(132.13)	344.33	THB	9.31E+12	THB	(1.18E-11)	3.08E-11
Employment	11	11	person	27,483,919	person	4.00E-07	4.00E-07

Note: * data of 2010, source: World Bank (2014)

Table 4: Sustainability scores of PCS and GCS

Items	Normalization		Levels of Importance	Sustainability Score	
	PCS	GCS		PCS	GCS
Environment	2.39E-10	2.65E-10	0.375	7.77E-11	9.28E-11
Economic	(1.18E-11)	3.08E-11	0.325	(4.43E-11)	1.15E-11
Social	4.00E-07	4.00E-07	0.300	1.20E-07	1.20E-07
Total				1.19988E-07	1.19989E-07

results in the sustainability score of PCS was 1.19988E-07 and GCS was 1.19989E-07. Furthermore, it can be concluded that GCS was more sustainable slightly at 1.00001 times that of PCS. This occurs because of the higher benefit of the economic aspect of GCS, although, on the other hand, it had a higher environmental impact than PCS did.

System Improvement Options

In order to find spots of improvement of the composting systems, sensitivity analysis was done by developing two scenarios which were based on a) reduction of gaseous emissions of the composting process by compost blanket application; b) gaseous emission reduction of transportation activity by fuel substitution from diesel to CNG (Compressed Natural Gas). Sensitivity analysis results are shown in Table 5.

Based on impact reduction on environment, its contribution to economic and social aspects was also analyzed. It can be seen that the scenario for reduction of gaseous emissions in the composting process and transportation sensitively reduced the impact of the initial system at 73% and 36% on PCS respectively, while on GCS it reduced the impact by 72% and 36%, respectively. For the economic aspect it sensitively impacted by reducing the impacts by 42% and 38% through gaseous emission reduction of composting process and of transportation, respectively, and on GCS it reduced impacts at 37% and 38%, respectively. Meanwhile, no impact reduction resulted in the social aspect for all scenarios, because existing employment could perform the two scenarios without changes.

Through similar steps of sustainability score determination of improved systems, it was found that improved PCS and GCS had higher sustainability scores than the initial PCS and GCS, which means that the improved system has enhanced the sustainability of the PCS and GCS. When comparing both improved systems it can be concluded that GCS was 1.00011 times more sustainable than PCS. This may have occurred because of higher reduction of environmental negative impact of improved GCS than improved PCS, although improved PCS gained higher economic benefits than improved GCS, whilst both systems were equaled on social impact.

By this finding, it was recommended to other community composting plant to apply gases emission reduction on composting system through compost blanket and fuel substitution application, which has proven could improve composting system operation into environmentally friendly and sustainable composting. Moreover, in order to be applied for larger scale in supporting sustainable agriculture, stakeholders, especially government, can use lower greenhouse gases emission as a requirement for compost product to get certification of green/ environmentally friendly compost.

Table 5: Sensitivity analysis results of PCS and GCS

Scenarios	PCS			
	Initial		**Improved**	
	GWP	**Damage Cost**	**GWP**	**Damage Cost**
	(kg CO_2 eq.)	**(THB)**	**(kg CO_2 eq.)**	**(THB)**
Gaseous emission reduction in composting plants	54.20	427.35	14.84	246.87
Gaseous emission reduction by fuel substitution	45.24	253.45	28.98	156.51
	GCS			
Gaseous emission reduction in composting plants	61.16	481.64	16.87	302.64
Gaseous emission reduction by fuel substitution	46.00	258.21	29.51	159.71

Conclusion

LCSA was applied to assess the sustainability performance of community composting of agricultural and agro industrial wastes. Comparison of products of community composting systems showed that GCS was more sustainable than PCS because it was more beneficial financially, although it released higher environmental impacts. In order to improve the sustainability performance for both systems, it was recommended that compost blanket and fuel substitution be applied to reduce gaseous emissions during composting system.

Acknowledgements

Thanks are addressed to the Graduate School, at Prince of Songkla University and the National Research Council of Thailand for financial support of this study. Thanks also to the Directory of Higher Education of the Educational and Cultural Ministry of the Republic of Indonesia that has provided a scholarship to study at Prince of Songkla University. Finally, thanks to the staff of the composting plants where the study was conducted.

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