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Environmental Impact Evaluation of Community Composting by Using Life Cycle Assessment: A Case Study Based on Types of Compost Product Operations

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Abstract

Life cycle assessment (LCA) was applied to evaluate environmental impacts contributed by 2 community composting systems, consisting of powder and granular compost production. The main raw materials of these composts were waste from agricultural and agro industrial activities, including animal manures, and solid waste from palm oil mills and rice mills. Data from field operations of both of the composting systems were collected and analyzed. Both composting systems were classified into 5 sub systems, consisting of raw material collection, composting process, electricity consumption, material transfer, and distribution of the compost product to consumers. Impact assessments of both composting systems revealed that the composting process sub system was the main contributor on impact categories of acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), and photochemical oxidation potential (POP), while on human toxicity potential (HTP) the distribution sub system was the main contributor. In comparing both systems, it was found that granular compost systems contributed a higher impact than powder compost systems, at 1.1 times on GWP, while the remaining sub systems had almost similar impacts. In order to improve composting systems, it is recommended that compost blanket and fuel substitution be applied, to enable gaseous emission reduction to the composting process and transportation operations.

Keywords: Agricultural and agro industrial waste, community composting, environmental impact, life cycle assessment

Introduction

In the last 10 years, many studies have investigated environmentally harmful gaseous emissions of the composting process [1-5]. Moreover, the life cycle assessment (LCA) tool has been introduced to assess the environmental impact of composting systems on life cycle thinking. Through various studies on composting technologies (windrows, tunnels, static piles, and composters), raw materials (organic fraction of municipal solid waste, pruning waste, yard waste, organic household waste, garden waste, and left over raw fruits and vegetables), and scales (home and industrial composting), it can be concluded that LCA has proven to be an effective tool to analyze the environmental impact of composting facilities [2].

Studies on composting system impacts revealed that composting processes were the main impact contributors to global warming, acidification, photochemical oxidation, eutrophication, ozone depletion, and human toxicity [2,3,6]. Moreover, the main sources of these were gaseous emissions, including volatile organic compounds (VOCs) and ammonia, and electricity consumption [2] and, for the broader scope of the system, distance of transportation, compost production and manufacturing were impacts to be considered [3].

LCA also has been applied to compare composting methods, in order to recommend system improvements. It compared composting systems as a solid waste management option with other methods [7-11], comparing 2 composting systems applying different technologies and/or with different scales of service [2,3,6]. Some recommendations from the studies were about options for system improvement for composting to be environmentally friendly, by improving waste purities to be composted, and improving treatment to reduce gaseous emissions [2], arranging collection and transportation distances [3], and substitution of fossil fuel based energy with alternative sources of energy [6].

Thailand is rich in agricultural and forestry resources. Agricultural activities play important roles in Thailand's economic growth. As a consequence, Thailand produces huge amounts of agricultural and agro industrial waste from rice, sugarcane, corn, cassava, oil palm, rubber, soybean, mung bean, and peanut bean plantations. Waste is generated with a potential utilized residue of 38.707 million tons/year nationally [12]. Meanwhile, from animal farming, in the 4 provinces of Nakhon Si Thammarat, Phatthalung, Surat Thani, and Songkhla, it was reported that 1.554 million tons/year of cow, buffalo, chicken, pig, and duck farm manure were generated [13].

Composting is a cheaper and simpler technology in solid waste management, and has played an important role in treating, minimizing, and utilizing organic wastes produced by municipalities, agricultural, and agro industrial activities. Organic fertilizers have proved to contribute lower emissions of greenhouse gases to the environment as compared to chemical fertilizers [6]. The Thai government's program started in 2006, with the aim to have one composting plant in each district; composting plants have been built to be managed and organized by communities to improve people's participation in producing organic compost, while advancing their own financial status [14,15]. Evaluation of 36 community composting plants in Southern Thailand found that they faced some problems, two of which were low efficiency of composting techniques and low quality of compost, and it was recommended that the composting technology and the compost quality be improved [16].

Community composting plants in Southern Thailand produce compost in powder and granular forms, which are then applied by rubber, oil palm, and fruit farmers. Powder compost is easy to apply to plants, but also easy to leach when a downpour occurs. On the other hand, granular compost is safe from being leached, since it is kept buried in land, but effort is needed to dig the land. Considering the weather in the region, generally, farmers apply powder compost in the summer and granular compost in the rainy season.

Considering further evaluation of community composting in Southern Thailand and its impact on the environment, this study was conducted in order to assess the environmental impact of the community composting system, in 2 different forms of compost products, namely, powder and granular, by applying LCA, as well as to find recommendations for system improvements, so as to become more environmentally friendly. This study revealed the environmental impact profile of community composting systems of agricultural and agro industrial waste practices, where other related studies were focused on industrial and home composting, with raw materials mainly from the organic fraction of municipal solid waste.

Materials and methods

Composting plant used for study

The representative community composting plant used for this study is located in Rattaphum district, Songkhla Province, Thailand. The plant produces two forms of compost product, powder and granular. Owned by a cooperative, the plant is managed by a manager under the auspices of the local community. The plant was built by the government in order to raise the community's economic status by participating in the production of bio-fertilizer for supporting sustainable agriculture. In supplying raw materials and marketing the products, this plant networks with other communities in neighboring provinces in Southern Thailand.

This plant treats agricultural and agro industrial waste, consisting of goat manure, chicken manure, bat manure, rice husk, rice bran, and decanter cake waste of palm oil mills, all mixed with phosphate rock and a bio-activator to produce high quality compost, with a maximum total production capacity from both systems of 300 tons per year.

The composting process is carried out in aerated static piles for 20 days for the powder product, and 24 days for the granular one, with intermittent aeration for one hour daily during the first 15 days, using a blower. No leachate is produced and no technology is applied for air emission reduction. Compost products are marketed for oil palm and rubber plantations, and for fruit farming. **Figure 1** shows a flowchart of related phases, with main facilities involved and emissions in the studied composting systems.

For both composting systems, raw and supporting materials are collected from several places in Songkhla, and neighboring provinces, Satun and Patthalung, using 6 wheel trucks and pick up vans. Raw materials are put on the stockpile manually. The raw materials, consisting of goat manure, chicken manure, bat manure, rice husk, rice bran, decanter cake palm oil, and phosphate rock, are loaded into the mixer using human power. Water and a liquid mixture, consisting of liquid bio fertilizer, molasses, and seeding, are mixed into a water tank and poured into the mixer. After being mixed evenly, the compost mixture is then discharged onto a conveyor belt to be placed on the open-channel with an 8,825 kg weight capacity. The first day process ends when one channel is fully loaded and is aerated for a one hour period.

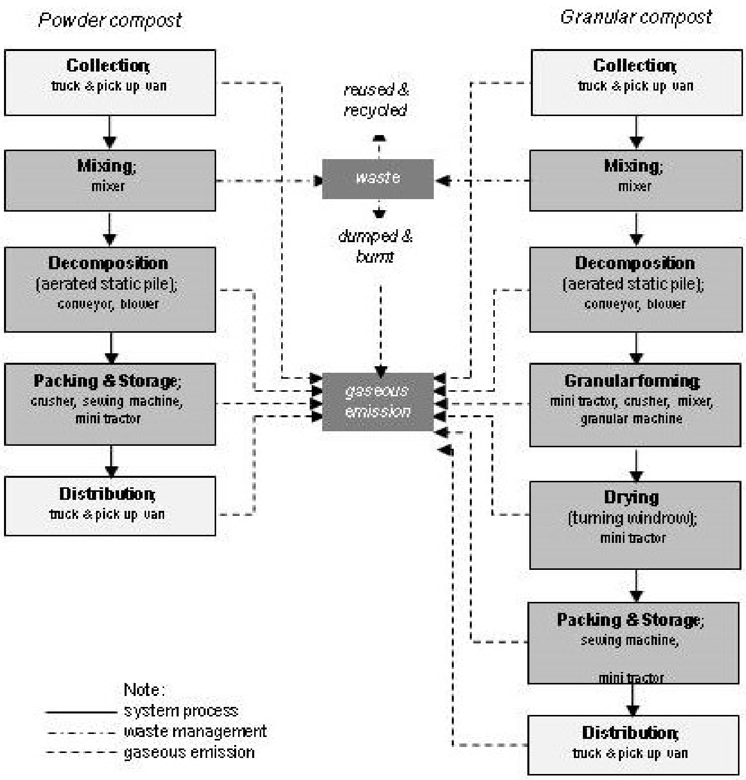

Figure 1 Flow chart of studied community composting systems.

Aeration is carried out in a similar way over the following 15 days. The pile is left without any treatment until the 19th day. On the 20th day, all the compost mixture is unloaded from the pile, and afterwards loaded onto the conveyor, which ends in the crusher to crush the compost to a homogeneous size for the powder compost product, ready for packaging. The compost is put into sacks, sewn by sewing machine, and weighted, before being placed into the warehouse by mini tractor. Distribution of the compost to the customers is done by the customers themselves but, for some nearby locations, distribution is done by the plant's pick up car. Transportation vehicles that are used for delivery are the same type as those used for raw materials collection.

Meanwhile, for the granular compost system, similar materials and phases are used as for the powder compost system on raw and supporting materials collection, the composting process until the end of the fermentation process, and distribution of the compost. After unloading the compost mixture from the composting pile, it is transferred by mini tractor into the granular forming station. The mixture is crushed by the crusher while piled on the floor, and then loaded into the mixer for additional mixing with a liquid mixture, in order to ease the forming process and to improve the quality of the product.

Afterwards, it is transferred to the pellet machine and then taken by conveyor to the granular plate machine to strengthen the form. The process finally ends with the sieve machine to sort the better granular formed compost. Granules that were not formed well are taken to the pellet machine to repeat the previous step. The day's work ends with the placing of granular compost on the drying station, which is transferred by mini tractor. For the next 3 days, the granular compost is turned 3 times daily using shovels. On the 24th day, the granular compost is put into sacks manually, sewn and weighted, and placed in the warehouse by mini tractor. In addition, all the machines that are used for the whole process use electricity.

LCA methodology

LCA is a technique to address the environmental impacts of a product, process, or service throughout the product's life cycle, which includes all stages, from raw materials to disposal of the product at the end of its life [17]. LCA consists of four main steps, of goal and scope definition, inventory analysis, impact assessment, and interpretation. This study was performed by applying SimaPro v.7.3.0 software [18].

Goal and scope definition

This study aimed to assess the environmental impact of community composting that treated agricultural and agro industrial waste. It was focused on comparisons of 2 types of compost product forms, namely, powder and granular. The functional unit (FU) was the management of 1 ton of agricultural and ago industrial waste (AAW) to produce compost. The functional unit was used as the base for composting systems comparison.

System boundaries of the study consisted of the collection of raw and supporting materials, composting processes, electricity consumption, the transfer of materials to the onsite plant and, finally, the distribution of compost products to customers. Impacts of materials and manufacturing of transportation vehicles, composting buildings, machinery, and supporting tools were out of the concern of this study, because they did not directly contribute to the composting system. Input and output flows of the system boundaries are shown in **Figure 2**.

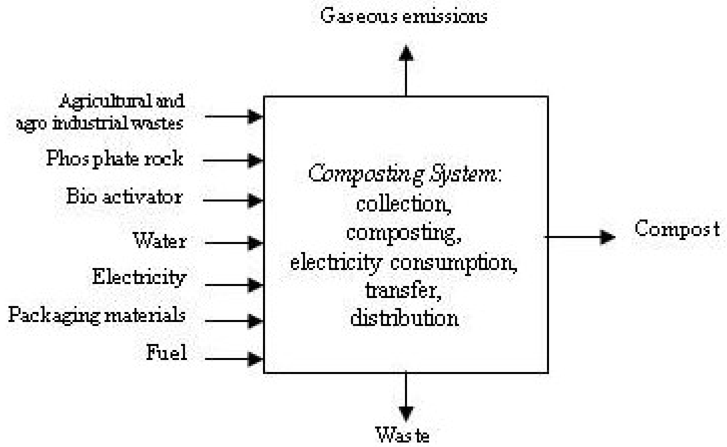

Figure 2 Input and output flows analyzed in community composting system.

Allocation procedure applied in relation to the composting system is complex, and involves multiple products and waste management systems. Since this study is concerned with powder and granular products, allocation was done based on proportions of mass loads in treatment of the main raw materials to become the products. Furthermore, in waste treatment, cut off methodology [3,4,19] was considered where environmental burden should be assigned to the system directly responsible for it.

Inventory analysis

Data inventory was obtained by a combination of field observation, laboratory analysis results, and calculations based on assumptions from related references. Data on distance of transportation, amounts of treated raw and supporting materials, waste, water consumption, compost production, and electricity consumption were obtained through field observation. Laboratory analysis was related to compost product quality and emissions of carbon dioxide and methane gases from the composting process. Sampling for compost product quality was collected by composite sampling method, and analyzed by following the manual for organic composts analysis [20]. Carbon dioxide and methane gas samples were collected by modified static flux chamber, following Andersen *et al*. [5], and analyzed with gas chromatography with a thermal conductivity detector (GC-TCD), with reference to Martinez-Blanco *et al*. [3].

Assumption was applied in the determination of emissions of dinitrogen monoxide and ammonia in the powder composting process. A combination of related studies on composting of manures and green wastes were referred to and applied to this study, with consideration of AAW in the present study consisting of 70 % manures and 30 % green waste. Meanwhile, emissions of dinitrogen monoxide and ammonia gases in the granular compost process were calculated based on the emissions from the powder compost process multiplied by the increased percentage of carbon dioxide emissions in the granular composting process, in comparison with the powder composting process.

Impact assessment

The impact assessment was performed by using the Centrum voor Milieukunde Leiden (CML) 2000 method, or CML 2 baseline 2000, which was developed by the Centre of Environmental Sciences at Leiden University. The impact categories that were used in this study were based on those considered in related studies by Cadena *et al*. [2] and Martinez-Blanco *et al*. [3]. The categories were abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP), human toxicity potential (HTP), and photochemical oxidation potential (POP). Other impact categories of fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, and terrestrial ecotoxicity were excluded, since no direct impacts were contributed by the composting system to these categories.

Interpretation

Results of impact assessment were interpreted through comparisons between sub systems of the compost system, and between compost systems, contribution analysis, uncertainty analysis, and sensitivity analysis, which led to recommendations on system improvement options.

Results and discussion

Inventory analysis

Compost quality of powder and granular compost products are represented in **Table 1**.

Table 1 Physicochemical properties of compost products.

Parameters	Units*	Powder compost	Granular compost	Standard[a]
Moisture content	%	19.41	20.26	≤ 35
Organic matter	%	33.13	30.10	≥ 30
pH		6.76	8.37	5.5 - 8.5
EC	ds/m	3.16	1.06	≤ 6
C/N ratio		12.33	10.84	≤ 20:1
N	%	1.56	1.07	≥ 1.0
P_2O_5	%	3.91	2.49	≥ 0.5
K_2O	%	1.23	0.92	≥ 0.5
As	mg/kg	3.755	4.77	≤ 50
Cd	mg/kg	0.76	0.64	≤ 5
Cu	mg/kg	96.94	77.65	≤ 500
Cr	mg/kg	6.72	5.68	≤ 300
Pb	mg/kg	4.87	9.00	≤ 500
Hg	mg/kg	LD	LD	≤ 2

Source: [a]: [20]
Note: *wet weight basis, LD: Lower than detection limit, LD of Hg was 0.010 mg/kg.

By comparing the results with those of organic fertilizer as issued by the Ministry of Agriculture and Cooperatives of Thailand [20], it can be seen that the quality of powder and granular composts have complied with all standard parameters. It can be concluded that the application of this composting operation can be promoted to improve compost quality in Southern Thailand, which was previously reported to have problems with poor quality, especially in the organic matter, moisture content, Cd, N, P, and K contents [14].

Data collected in the inventory phase of both systems are shown in **Table 2**.

Table 2 Inventory analysis of two compost product systems.

Stages	Elements	Units	Powder	Granular
Input				
Collection	total	Tkm	64.08	64.11
raw materials	truck and pick up van	Tkm	63.89	63.92
supporting materials	truck and pick up van	Tkm	0.19	0.19
Composting				
raw material	AAW	Kg	1,000.00	1,000.00
	phosphate rock	Kg	142.39	142.39
	bio-activator mixture	Kg	6.98	7.90
water consumption	water	Kg	98.38	111.33
electricity	machinery	kWh	5.72	11.80
transfer material	mini tractor	Tkm	0.18	0.37
Distribution compost	truck and pick up van	Tkm	148.05	152.00
Output				
Gaseous emissions	CO_2	Kg	99.25	107.55
	CH_4	Kg	0.49	0.69
	NH_3	Kg	1.54[a]	1.69[b]
	N_2O	Kg	0.15[a]	0.16[b]
Compost product	compost	Kg	987.03	1,013.30
	packaging	Kg	4.01	4.12
Waste	total	Kg	4.92	4.99
dumped	plastic (bag, rope, packaging)	Kg	0.66	0.67
reused	plastic (bag, rope)	Kg	4.24	4.30
recycled	Cardboard	Kg	0.02	0.02

Source: field observation, laboratory analysis and interview
Note: [a] = from related studies by calculation of 70 % manure and 30 % green waste; [b] = assumption based on the increase of carbon dioxide emissions of the granular composting process of this study as 1.1 times that of the powder composting process.

These data figured some ratios related to the efficiency of the composting system regarding compost production (ton compost products/ton AAW), gaseous emissions (kg of gaseous/ton AAW), waste generation (kg of waste/ton AAW), other raw material consumption (kg phosphate rock/ton AAW and kg of bio-activator mixture /ton AAW), resource consumption (kWh electricity/ton AAW, kg water/ ton AAW), and transportation activities (tkm/ton AAW).

Table 2 revealed that, in utilizing 1 ton of AAW, granular compost system, more bio-activator mixture, water, and electricity than for the powder compost system was consumed. Higher bio-activator and water consumption was attributed to more bio-activator involved for granular formation through twice the amount of bio-activator mixture, mixed with the composted waste. The first time was before the decomposition process, and the last was before entering the granular machine. Higher electricity consumption was related to more machinery and working hours to operate for the granular compost system, which used a granular forming machine and mixer twice, whilst for the powder compost, no forming machine was needed, and the mixer was used only once.

Moreover, the granular system resulted in more compost production, gas emissions, and transfer and distribution operations than did the powder compost. Higher compost production was related to weight gain by the additional mixing of composted waste with water and bio-activator mixture before the granular forming phase. This phase was also responsible for a longer composting process time of the granular system than of the powder system which, furthermore, contributed to higher gas emissions. Higher operation of transfer was attributed to the additional step of the drying phase for granular composting, when the compost mixture was transferred from the granular forming station to the drying station.

Finally, powder and granular compost systems consumed similar amounts of phosphate rock, almost similar waste generation, and collection operations. A similar amount of phosphate rock needed to be mixed with AAW as compost mixture, and an almost similar amount of supporting materials was involved in the composting production.

In comparison with related studies of composting plant scales, as reported by Martinez-Blanco *et al.* [3] and Colon *et al.* [4], the present study reports that less water and electricity were consumed than in industrial composting, but more than in home composting. On the total transportation activity, this study observed higher value performance than in industrial and home composting practices. It could have occurred because the location of material sources and customers of the present study were located at longer distance than related studies. When comparing gas emissions, it was observed that higher concentrations of ammonia, methane, and dinitrogen monoxide were released than in industrial and home composting. It could have happened because of the raw material composition, 70 % of which was from manure, and the rest from green waste, whilst related studies only treated organic or green wastes. Finally, it was seen that smaller amounts of waste were generated than in industrial and home composting. This related to the application of waste management, such as reusing and recycling, and moreover, related to the homogeneous raw materials studied, which meant no pretreatment was needed to reduce material size in order to ease the composting process.

Impact assessment

The impacts of both composting product systems are summarized in **Tables 3** and **4**.

Table 3 Impact characterization results for powder compost product system.

Impact category	Unit/FU	Total	Collection	Composting	Electricity	Transfer	Distribution
AP	kg SO_2 eq.	2.643	0.063	2.464	0.006	0.0001	0.109
	%	100	2.40	**93.23**	0.23	0.01	4.13
EP	kg PO_4^{3-} eq.	0.582	0.015	0.539	0.001	3.5E-05	0.026
	%	100	2.64	**92.62**	0.19	0.01	4.54
GWP	kg CO_2 eq.	102.740	16.642	54.200	3.263	0.0384	28.597
	%	100	16.20	**52.75**	3.18	0.04	27.83
HTP	kg 1,4-DB eq.	0.557	0.144	0.154	0.011	0.0003	0.248
	%	100	25.89	27.67	1.89	0.06	**44.49**
POP	kg C_2H_4	0.005	0.001	0.003	9.2E-05	1.9E-06	0.001
	%	100	15.59	**55.82**	1.76	0.04	26.79

Table 4 Impact characterization results for granular compost product system.

Impact category	Unit/FU	Total	Collection	Composting	Electricity	Transfer	Distribution
AP	kg SO_2 eq.	2.892	0.064	2.704	0.012	0.0003	0.112
	%	100	2.20	**93.49**	0.43	0.01	3.87
EP	kg PO_4^{3-} eq.	0.636	0.015	0.592	0.002	7.4E-05	0.027
	%	100	2.42	**92.95**	0.36	0.01	4.26
GWP	kg CO_2 eq.	113.980	16.653	61.160	6.738	0.0805	29.348
	%	100	14.61	**53.66**	5.91	0.07	25.75
HTP	kg 1,4-DB eq.	0.590	0.144	0.169	0.022	0.0007	0.254
	%	100	24.45	28.66	3.68	0.12	**43.09**
POP	kg C_2H_4	0.007	0.001	0.004	0.0002	4.0E-06	0.001
	%	100	12.44	**62.68**	2.89	0.06	21.93

Impact categories studied were related to ADP, AP, EP, GWP, ODP, HTP, and POP, but since the characterization results of ADP and ODP were zero, these categories were excluded on further analysis. On both systems, transportation activities, including collection, transfer, and distribution steps, contributed impacts on the AP, EP, GWP, HTP, and POP impact categories, which were attributed to gaseous emissions (CO, CO_2, NO_2, SO_2, VOCs, and CH_4) from the fuel consumption of diesel trucks and pick up vans. Similar impact categories were contributed by the composting process, which impacted on AP, EP, GWP, HTP, and POP, which related to gaseous emissions during the process of decomposition, consisting of CH_4, NH_3, and N_2O. Meanwhile, CO_2 emissions from the composting process were not considered as greenhouse gases, because they came from a biogenic source and were negligible [7]. Finally, electricity consumption contributed to all impact categories, and was considered to indirectly impact the local environment, since it was produced by power plants which were located in different regions. In Thailand, sources of energy for electricity are a combination of natural gas, lignite, hydro power, fuel oil, and renewable energy power plants [21]. Power plant operations were impacted in all categories by gaseous emissions, such as CO, CO_2, CH_4, N_2O, NO_2, SO_2, VOC, and particulate matter (PM).

Interpretation

As a result of the characterization step, the impacts of specific system phases were ranked and analyzed. **Tables 3 - 4** present the amounts of the impacts of both the powder system and granular system, respectively. Generally, the composting process and distribution were the main impacting sub systems. **Table 3** depicts that, in the powder compost system, all sub systems contributed impacts to all categories. The total impact in AP at 2.643 kg SO_2 eq./FU was mainly supplied by the composting process, at 2.464 kg SO_2 eq./FU (93.23 %), followed by the distribution, collection, electricity, and transfer sub systems. Similar patterns were found on impact categories of EP, GWP, and POP, with the composting process giving the highest contribution at 0.539 kg PO_4^{-3} eq. /FU (92.62 %), 54.200 kg CO_2 eq./FU (52.75 %), and 0.003 kg C_2H_4/FU (55.82 %), respectively. In the HTP category, total impact was 0.557 kg 1,4-DB eq./FU, 44.49 % of it contributed by the distribution sub system, which was then followed by the composting process, collection, electricity, and transfer sub systems. In addition, other sub systems included collection, electricity, and transfer, contributing an impact less than 25.9, 3.2, and 0.1 % of the total impact of each category, respectively.

In the granular system, as shown in **Table 4**, all sub systems were also responsible for all impact categories. Similar patterns as for the powder compost system were observed, on AP, EP, GWP, and POP, and the composting process was responsible for the highest impacts, followed by distribution, collection, electricity consumption, and transfer sub system. The composting process was the highest contributor for AP (93.49 %), EP (92.95 %), GWP (53.66 %), and POP (62.68 %), while the distribution sub system contributed the highest impact for HTP (43.09 %). Collection, electricity, and transfer sub systems were responsible for less impact in all categories, with the percentage of impacts at less than 24.5, 6.0, and 0.2 % of the total impact of each category, respectively.

In comparison with related studies of LCA application on composting, it was found that the present study contributed environmental impacts in similar impact categories, including AP, EP, GWP, HTP, and POP [2,3,6]. The present study has drawn similar findings to related studies, concluding that one of the main sources of environmental impact was gaseous emissions of the composting process [2].

The impact comparisons of powder and granular compost systems are depicted in **Figure 3.** It can be seen that the total effect on all impact categories of the granular compost system were higher than the powder compost system, especially in the GWP category, was which higher at 11.2 kg CO_2 eq. or 1.1 times. In comparing sub systems of both compost systems, the highest difference of both systems was shown in composting sub systems on the GWP category, with 7.0 kg CO_2 eq. difference, while other impact categories and subsystems remained similar. The differences occurred in contribution of emissions of dinitrogen monoxide and methane from the composting process, which were higher by 1.1 and 1.5 times in the granular compost system than in the powder compost system, respectively.

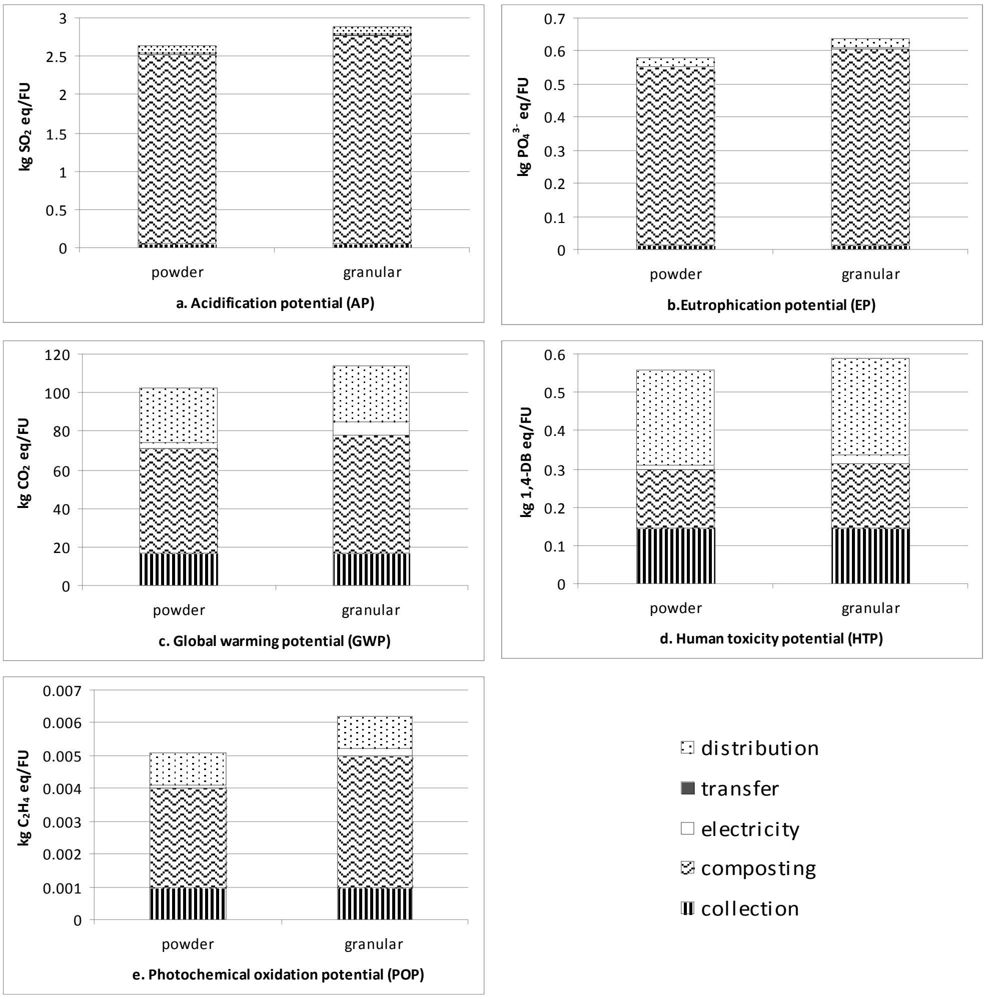

Figure 3 Comparison of environmental impacts of powder and granular compost systems.

Moreover, **Figure 3** also shows that transportation activities, especially collection and distribution sub systems, contributed the second highest impact of all impact categories. Comparison of sub systems of both systems showed that distribution for the granular compost system was responsible for a higher impact on the GWP category, at 0.8 kg CO_2 eq. more than the powder compost system. This was attributed to the emission of CO_2, CO, and methane from diesel fuel consumption, which in the granular compost system operated a bigger distribution operation, namely 1.03 times more than the powder compost system.

In detail, impacts of the composting processes of both compost systems on AP, EP, and HTP were contributed fully by the emission of ammonia. The impact on POP was contributed fully by the emission of methane, whilst the impact on GWP was contributed by dinitrogen monoxide and methane emissions. Different portions of both emissions were found in both composting processes, and dinitrogen monoxide was responsible for 82 and 77 % of the total impact on GWP of powder and granular composting processes, respectively, while methane was responsible for the remaining percentages. Methane was responsible for more portions on the granular composting process than dinitrogen monoxide was, because its emission ratios were higher than those of the powder composting process.

Moreover, for transportation activities, impacts were attributed to gaseous emissions from diesel fuel consumption. Nitrogen oxides, carbon dioxide, carbon monoxide, and sulfur dioxide were responsible for higher contributions to all impact categories. Nitrogen oxide was responsible for the highest percentage of the total impact on EP (100 %), HTP (98.5 %), and AP (93 %), respectively, while carbon dioxide only contributed to GWP, and was responsible for 99.7 % of it. Carbon monoxide was responsible for 78.3 and 0.2 % of the total impact on POP and GWP, while sulfur oxide was responsible for 21.4, 7, and 0.2 % of the total impact on POP, AP and HTP. In addition, methane was responsible for lower percentages of the total impact on POP (0.3 %) and GWP (0.1 %), while PM only contributed 1.3 % of the total impact on HTP.

Furthermore, impacts of power plant operations to generate electricity were mostly contributed by natural and lignite power plant operations. Natural gas power plants were responsible for higher contributions on all impact categories, including AP (52 %), EP (67 %), GWP (60 %), and HTP (66 %), while on POP, the highest contribution was from a lignite power plant, at 62 %. Fuel oil power plants were responsible for contributing less than 4 % of the total impact in all impact categories. A renewable energy power plant was responsible for only 4 % of the total impact of POP, while a hydro power plant was considered as having no contribution to any impact categories. Higher impacts from a natural gas power plant showed higher emissions of nitrogen oxide which impacted on AP (48 %), EP (67 %), and HTP (66 %), while higher emission of carbon dioxide had a higher impact on GWP (60 %). Emission sulfur oxide from a lignite power plant was responsible for higher impacts on POP (61 %).

In order to find critical points for system improvement, sensitivity analysis was done by consideration of reduction on composting gaseous emissions (25 and 50 % reduction), reduction of transportation gaseous emissions (no CH_4 and SO_2, and reduction of CO_2, CO and NO_2 by 25 and 50 %), reduction of electricity consumption by 25 and 50 %, and transfer distance reduction by 25 and 50 %. The results of the sensitivity analysis revealed that only reduction of gaseous emissions of composting processes and transportation activities sensitively reduced impacts. Reduction of gaseous emissions from composting processes significantly reduced impacts on impact categories, while emission reduction on transportation activities only sensitively reduced impacts on GWP, HTP and POP.

Therefore, due to system improvements, this study recommends that, firstly, as the main sub system that contributed mostly impacts on AP, EP, GWP, and POP, it be necessary that composting processes that produce gaseous emissions, including methane, ammonia, and dinitrogen monoxide be improved. Some technology that has been introduced and applied to minimize the emissions released into the air includes bio-filtration [2,3,22], compost blanket from compost product with a thickness of 15 cm [23,24], and the use of additional materials, such as magnesium and phosphate salt mixed with the compost substrates in order to bind ammonia [25]. Since this plant is a community composting scheme, it might be that the application of compost blanket is the best applied technology to be implemented.

Transportation activities, including distribution of compost, gave environmental impacts that depended on the type of vehicles and fuel consumption. By considering a widespread non fossil fuel oil campaign in Thailand, supported by automobile dealers, the opportunity to reduce the impacts of transportation activities can be based on substitution of fuel type. By considering commercial provisions of alternative fuels, it is recommended that there be a shift from diesel fuel to biodiesel or LPG (Liquefied Petroleum Gas) and CNG (Compressed Natural Gas) for pick up vans, which would be more applicable to the technology and be more economical.

Conclusions

Two different forms of compost product, powder and granular, have been studied, and their environmental impacts assessed by applying LCA. In the present study, LCA has proven effective to address the environmental impacts of the community composting systems, and found some critical points to be improved to enable a better system that would be more environmentally friendly.

In the whole composting system, the main impacted sub system for both forms was the composting process, followed by the distribution, collection, electricity consumption, and transfer sub systems. Composting processes were responsible for the highest portion of impacts on AP, EP, GWP, and POP, while for the HTP, the distribution sub system was responsible for the highest contribution.

When comparing the powder and granular compost systems, it was found that the latter had a higher impact on the environment than the former, at 1.1 times in the GWP impact category, whilst other impact categories, including AP, EP, HTP, and POP, were similar.

In order to improve the composting systems to become environmentally friendly, reduction of gaseous emissions from composting processes and transportation activities by compost blanket application and diesel fuel substitution to biodiesel or LPG and CNG are recommended.

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