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Project title	Life Cycle Assessment (LCA) of vermicomposting from paper cup waste and rain tree leaves with coffee ground and cow dung as bulking agents

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Department Environmental Science

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Life Cycle Assessment (LCA) of vermicomposting from paper cup waste and rain tree leaves with coffee ground and cow dung as bulking agents

Nisachol Kulsirilak

A Senior Project Submitted in Partial Fulfillment of the Requirements for the Bachelor's Degree of Science Program in Environmental Science,

Department of Environmental Science,

Faculty of Science, Chulalongkorn University,

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บทคัดย่อ

งานวิจัยนี้มีจุดประสงค์เพื่อ 1)ศึกษาเปรียบเทียบการประเมินวัฏจักรชีวิตผลิตภัณฑ์ของปุ๋ยหมักมูลไส้เดือน 5 ตำรับการทดลอง และ 2)ศึกษาความคุ้มค่าทางเศรษฐศาสตร์ของปุ๋ยหมักมูลไส้เดือนจากมูลฝอยที่เกิดขึ้นภายในจุฬาลงกรณ์มหาวิทยาลัย การศึกษาเปรียบเทียบวัฏจักรชีวิตผลิตภัณฑ์ของปุ๋ยหมักมูลไส้เดือน 5 ตำรับ ได้แก่ T1, T2, T3, T4 และ T5 โดยแต่ละตำรับประกอบด้วยขยะถ้วยกระดาษร้อยละ 100, 95, 90, 85, 80 และใบจามจุรีร้อยละ 0, 5, 10, 15, 20 ตามลำดับ ในทุกตำรับการทดลองจะมีการใส่มูลวัวร้อยละ 20 และกากกาแฟร้อยละ 45 ของมวลวัตถุดิบตั้งต้น การวิเคราะห์ผลกระทบครอบคลุมตั้งแต่กระบวนการได้มาซึ่งวัตถุดิบไปจนถึงกระบวนการหมักปุ๋ยมูลไส้เดือนโดยใช้ซอฟต์แวร์ SimaPro เวอร์ชั่น 8.0.5 ในการวิเคราะห์ โดยผลศึกษาจะแบ่งผลกระทบทางสิ่งแวดล้อมออกเป็น 4 ด้านได้แก่ การทำลายทรัพยากร ภาวะความเป็นกรด ยูโทรฟิเคชั่น และการเกิดภาวะโลกร้อน จากการศึกษาพบว่า ในตำรับการทดลองที่มีปริมาณถ้วยกระดาษลดลงจะส่งผลให้เกิดโดยผลกระทบต่อสิ่งแวดล้อมลดลงจาก 0.001156 ถึง 0.000938 kg. Sb eq, 0.000615 ถึง 0.000493 kg. SO_2 eq, 0.000337 ถึง 0.00027 kg. PO_4^{3-} eq, 0.146883 ถึง 0.117976 kg. CO_2 eq ในผลกระทบแต่ละด้านตามลำดับ เนื่องจากการใช้ถ้วยกระดาษในการหมักปุ๋ยนั้นจะต้องผ่านกระบวนการตัดย่อยถ้วยกระดาษโดยเครื่องย่อยกระดาษ ซึ่งต้องใช้พลังงานไฟฟ้าค่อนข้างมาก นอกจากนั้น งานวิจัยนี้ได้ทำการประเมินความคุ้มค่าทางเศรษฐศาสตร์ของปุ๋ยหมักมูลไส้เดือนในตำรับการทดลองที่ 5 ซึ่งส่งผลกระทบต่อสิ่งแวดล้อมน้อยที่สุด พบว่าการหมักปุ๋ยมูลไส้เดือนจากใบจามจุรี และ ขยะถ้วยกระดาษสามารถสร้างมูลค่าให้กับมูลฝอยได้ และสามารถคืนทุนได้ในระยะเวลาประมาณ 2 ปี 11 เดือน

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Project title	Life Cycle Assessment (LCA) of vermicomposting from paper cup waste and rain tree leaves with coffee ground and cow dung as bulking agents
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ABSTRACT

The aim of this research was 1) to study the comparative of the LCA of 5 treatment of vermicomposting products. 2) to study the economic performance and worthiness of vermicompost from paper cup waste and rain tree leaves in Chulalongkorn University. Comparative study of LCA of 5 treatments include T1, T2, T3, T4 and T5. Each treatment consists of 100, 95, 90, 85, 80% of paper cup waste and 0, 5, 10, 15, 20% of rain tree leaves respectively. Every treatment was added cow dung and coffee grounds to use as bulking agents. The impact assessment covered raw material acquisition, transportation and vermicomposting process by using SimaPro 8.0.5 to analyze the 4 environmental impacts. The results showed that all impacts were decreased from 0.001156 to 0.000938 kg Sb eq, 0.000615 to 0.000493 kg SO_2 eq, 0.000337 to 0.00027 kg PO_4^{3-} eq, 0.146883 to 0.117976 kg CO_2 eq in terms of abiotic depletion, acidification, eutrophication and global warming respectively in T1 to T5 due to the paper cup waste must be cut by a paper shredder which consumed electricity. Furthermore, the economic feasibility of T5 of vermicomposting which has the least impact on the environment showed that the vermicomposting from solid waste in Chulalongkorn University could create value for solid waste which payback period was about 2 years and 11months.

Key word: Life Cycle Assessment (LCA), Vermicomposting, Paper cup waste, Rain tree leaves

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CONTENTS

	Page
Abstract in Thai……..……………………………………..………………	i
Abstract in English…………………………………………………………	ii
Acknowledgement……………………...……………………….…………...	iii
Contents……………………………………………………………………...	iv
List of Tables……………………………………..……………………….	v
List of Figures………………………………………………………………	vi
Chapter 1 Introduction……………………………………………………..	1
1.1 Introduction…………………………………………………………	1
1.2 Objectives………………………………………………………....	2
Chapter 2 Theory and Literature Review…..…………..………………..	3
2.1 Definition of Life Cycle Assessment...…………………………...	3
2.2 Phase of Life Cycle Assessment………………………..............	4
Chapter 3 Material and method………………………………….…………..	11
3.1 Analysis of Life Cycle Assessment (LCA)………………………	11
3.1.1 Goal and scope……………………………………………....	11
3.1.2. Life Cycle Inventory (LCI)………………………………..	12
3.1.3 Life Cycle Impact Assessment (LCIA)……….…………….	14
3.1.4 Interpretation……………………………………………......	15
3.2 Economic feasibility……………………………………………..	15
Chapter 4 Results and Discussion…………………………………..…..	17
4.1 The environmental impacts of vermicomposting ………………..	17
4.2 Abiotic depletion impact of each treatment………………………	19
4.3 Acidification impact of each treatment…………………...…….	21
4.4 Eutrophication impact of each treatment…………………………	22
4.5 Global warming impact of each treatment………………………..	23
4.6 Economic feasibility of vermicomposting………………………..	25
4.6.1 Vermicomposting cost……………………………………….	25
4.6.2 Waste transportation cost……………………………………	25
4.6.3 Other transportation cost…………………………………….	26
Chapter 5 Conclusions…………………………………………………...	29
5.1 Conclusions ……………………………………………………….	29
5.2 Recommendation…………………………………………………	30
References…………………………………………………………………	31
Researcher Profile……………………………………………..…………	33

LIST OF TABLES

	Page
Table 2.1 Commonly used life cycle impact categories……………………..	7
Table 4.1 Environmental impact of vermicomposting of each treatment……..	17
Table 4.2 Abiotic depletion impact data…………………………………...	19
Table 4.3 Acidification impact data………………………………………..	21
Table 4.4 Eutrophication impact data……………………………………...	22
Table 4.5 Global warming impact data…………………………………….	24
Table 4.6 Distribution of vermicomposting costs…………………………….	25

LIST OF FIGURES

	Page
Figure 2.1 Phases of Life Cycle Assessment………………………………….	4
Figure 3.1 The system boundaries of study include raw material procurement to vermicomposting process…………………………………………………	11
Figure 3.2 Life Cycle Inventory (LCI) of vermicompost……………………	13
Figure 4.1 The comparative graph of the environmental impacts of vermicomposting of each treatment………………………………………..	18
Figure 4.2 Abiotic depletion impact of each treatment of vermicomposting…	19
Figure 4.3 Acidification impact of each treatment of vermicomposting……....	21
Figure 4.4 Eutrophication impact of each treatment of vermicomposting……	22
Figure 4.5 Global warming impact of each treatment of vermicomposting…..	23

Chapter 1
Introductions

Introduction

Municipal solid waste management is major environmental issue all over the world especially in Thailand. The amount of municipal solid waste in 2017 is 27.40 million tons or 75,046 tons per day and there were still about 5.34 million tons of residue for disposal (Pollution Control Department, 2018).

Realization of solid waste management issues at national level and international level, thus Chulalongkorn University establishes Chula Zero Waste Project to guide the sustainable waste management within the University and Klomklang (2018) studied vermicomposting from paper cup waste and rain tree leaves to sustainably manage waste in the University. That research result showed that 5 treatments of vermicomposting qualities consisted of 8 parameters: pH, electricity conductivity, total nitrogen, available phosphorus, exchangeable potassium, total organic carbon and total organic matter. The research conclusion showed all treatments of vermicomposting from paper cup waste and rain tree leaves could be used as soil amendment material.

Vermicomposting generated environmental effects in all processes include raw materials transportation, raw material preparation and vermicomposting process. These methods can emit greenhouse gas and other environmental pollution that cause health and environmental impacts, hence Life Cycle Assessment (LCA) was considered in this research to evaluate environmental impact of waste management between five treatments of vermicomposting from paper cup waste and rain tree leaves with cow dung and spent coffee ground as bulking agents.

Objectives

1. To compare the LCA of each treatment of the vermicompost from paper cup waste and rain tree leaves.
2. To analyze the economic performance and worthiness of vermicompost from solid waste in Chulalongkorn University.

Chapter 2
Theory and literature review

2.1 Definition of LCA

LCA (Life Cycle Assessment) is a method for analyzing the environmental impact of a product from the process of acquiring raw materials, transportation, production processes to final waste disposal. International Organization for Standardization (ISO) defined the meaning of LCA in the ISO 14040 as collection and evaluation of input and output substances, including environmental impacts that are occurred in the system throughout the life cycle which can be said that considering products from birth to death (Cradle to Grave). That is, since the acquisition of raw materials, manufacturing, product distribution, product use and disposal of products after use by measuring in every step of the raw material and the energy used in productive processes including the amount of waste released into the environment which can evaluate and indicate the effects that have an impact on the environment to minimize the impact And can set guidelines for further environmental management (Warnphen, 2018).

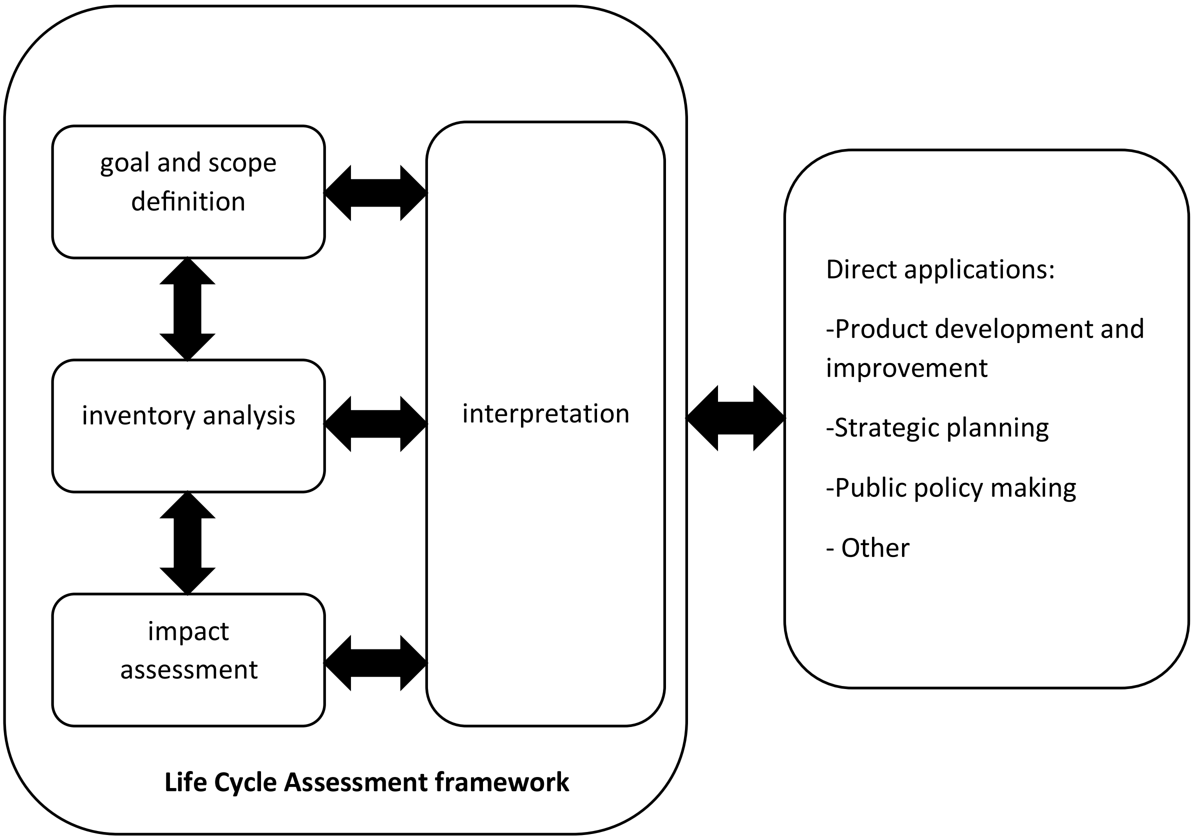

Figure 2.1 Phases of Life Cycle Assessment (ISO, 2006)

2.2 Phase of Life Cycle Assessment

There are four steps of Life Cycle Assessment: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation (Sampattagul, 2012; Tonini et. al., 2018).

1. Goal and scope definition is the first important step of LCA. Determining goal and scope must be clear, not obscure, cover the objectives and can determine the scope of the study that consist of Goal and Scope, Product Function, Functional Unit, System Boundary and Product System.

Determining goal of LCA study must be clear, not ambiguous, define reasons of studying, result and applying the study. Determining scope of this study must be consistent with the goal and cover the product function, functional unit, system boundary, hypothesis and limitation of study.

Scope definition must specify the product function and characteristics because one product may have different functions. For an easy life cycle assessment need scope definition which according to aim of study.

Functional unit is set up to use as the basis for data collection. It is important to compare the results of the life cycle assessment, which is necessary in comparison between the product process or products that are combined into a single product so that the data have the same functional unit.

System boundary is defined as the boundary between the product system and the environment or with other product systems. The product system is a system that is modeled from many subprocesses are combined with the flow of products or waste that must be treated for each subprocess as a link. In addition to the product system simulation, preparation of flow diagrams is necessary and useful for study. System boundary is as follow:

- Gate to Gate: impact assessment that is specific to a process from the entire production chain.
- Gate to Grave: impact assessment that start from production process until getting products including transportation, product distribution, product use and waste disposal.
- Cradle to Gate: impact assessment throughout the life cycle since getting raw material until production process.
- Cradle to Grave: impact assessment throughout the life cycle since getting raw material until waste disposal.
- Cradle to Cradle: special form of impact assessment that considers the impact of the recycling process.

2. Life Cycle Inventory Analysis (LCI) is a collection and calculation of data obtained from every process as defined in the scope. Flow chart is created and

calculated quantified inputs and outputs of system. These inputs and outputs include energy input, raw materials, product, waste, environmental pollutions.

3. Life Cycle Impact Assessment (LCIA) aims to assess the environmental impact of the product system based on data obtained from the life cycle inventory analysis by classifying the grouping impact and selecting of the indicators of the group. The result will indicate which impact groups are important or causing the most severe consequences in order to prepare information for use in translating the environmental impact of the product system. There are three main categories that Life Cycle Impact Assessment focus on: human health, ecological health, and resource depletion (SAIC, 2006). Table 2.1 showed commonly used impact categories.

Table 2.1 Commonly used life cycle impact categories (SAIC, 2006)

Impact Category	**Scale**	**Relevant LCI data**	**Common Possible Characterization Factor**	**Description of Characterization Factor**
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100- or 500-year potentials.
Stratospheric Ozone depletion	Global	Chlorofluorocarbons (CFCs)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SO_x) Nitrogen Oxides (NOx) Hydrochloric Acid (HCl) Hydrofluoric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents.
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents.
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxidant Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents; uses multimedia modeling, exposure pathways.

Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents; uses multimedia modeling, exposure pathways.
Human Health	Global Regional Local	Total release to air, water, and soil	LC_{50}	Converts LC_{50} data to equivalents; uses multimedia modeling, exposure pathways.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications	Land Availability	Converts mass of solid waste into volume using an estimated density
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve

Mandatory processes

Classification is a procedure used to classify inventory into environmental impact groups. For example, sulfur dioxide can be classified as an acidic effect and effects on human health. Therefore, the amount of sulfur dioxide is divided into half which is used to calculate the potential effect of each impact group (Kanya, 2008).

Characterization is a process that transforms the LCI results by using conversion factors to calculate the potential impact as an equivalent factor that is expressed as an indicator of human health and ecology and compares the results of each type, environmental impacts. (SAIC, 2006) Potential environmental impacts are calculated using the conversion factor as an equation (2.1) (Bunprom and Thirawanutpong, 2013).

$$EPj = \Sigma (Qi \times EFij) \qquad (2.1)$$

Where:

EPj = Environmental Impact Potential (kg Substance Equivalent)

Qj = Quantity of Substance (kg Substance j)

EFij = Equivalent Factor (kg Substance Equivalent/kg Substance j)

For example, conversion factors are used to convert the LCI results which are the greenhouse gases into the same equivalent which the combination of the result will express the overall global warming potential (SAIC, 2006).

Optional processes

Normalization is a procedure used to show the overall magnitude of the environmental impact from a process or activity, calculated using the equation (2.2) (Bunprom and Thirawanutpong, 2013).

$$NPj(product) = EPj/(T \times ERj) \tag{2.2}$$

Where:

NPj(product) = Normalized Environmental Impact (Person)

T = Lifetime of Product (Year)

ERj = Normalization Reference (kg Substance Equivalent/Person/Year)

Grouping is the procedure used for sorting or sequencing LCIA data into a specific group for better interpretation, which has two methods for grouping. (SAIC, 2006):

1. By characteristics such as emissions or location
2. By ranking system such as high, medium and low priority

Weighting is a procedure used to determine the hierarchical weight of the environmental impact, which can be divided into 3 categories: human health, ecological health and resource loss by calculating using the equation (2.3). (Bunprom and Thirawanutpong, 2013).

$$WPj = WFj \times NPj \tag{2.3}$$

Where:

WPj = Weighted Environmental Impact Potential (Person for Target Year; Pt)

WFj = Weighting Factor

NPj = Normalized Environmental Impact (Person)

4.interpretation is analyzing and summarizing results, explaining the limitations and recommendations and summarizing the translation of the complete study that can be easily understand and consistent with the goals and scope.

Chapter 3
Materials and Methods

3.1 Analysis of Life Cycle Assessment (LCA)

The vermicomposting process for paper cup waste and rain tree leaves can reduce Chulalongkorn University's MSW and turn it into soil amendment material. However, the vermicompost production process also requires energy, chemicals, and resources that directly and/or indirectly affect the environment, such as transportation, causing air pollution with both dust and greenhouse gases (Kucharoen, 2016). Therefore, the environmental impact is investigated throughout this process by LCA. This research assesses the best vermicompost from five treatments that pass the criteria set by the Department of Agriculture.

3.1.1 Goal and scope

This study's aim is to compare the environmental life-cycle impact of paper cup waste and rain tree leaf management between 5 ratios of vermicomposting from paper cup waste and rain tree leaves. The analysis used follows the phases of LCA, which cover from raw materials procurement to the vermicomposting process called "cradle to gate", as shown in Figure 5.

The functional unit will be defined as the mass of vermicompost (1 ton of waste)

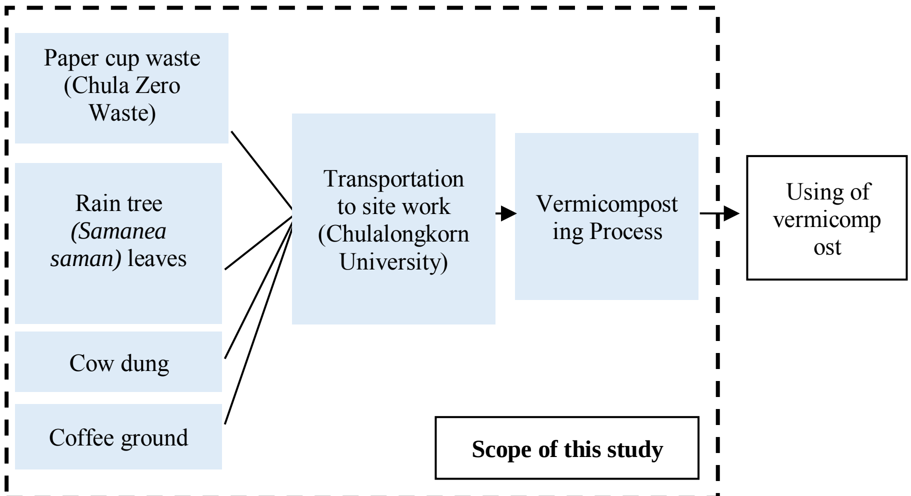

Figure 3.1 The system boundaries of study include raw material procurement to vermicomposting process

3.1.2. Life Cycle Inventory (LCI)

3.1.2.1 Data preparation

Paper cup waste was collected from the Chula Zero Waste Project, Chulalongkorn University. Rain tree leaves were collected from the Chulalongkorn University campus. Cow dung is brought from Thunhikorn shop and coffee ground was bought from Terracotta coffee shop, Chulalongkorn University.

The life cycle inventory (LCI) data of vermicomposting was gained from lab scale study of research of managing waste in Chulalongkorn University by vermicomposting. All treatments of vermicomposting were reported directly from the study

Assumptions

1. Raw materials transportation vehicle is assuming as light commercial vehicles (LCV)* which using diesel as fuel.

   * Light commercial vehicles are the vehicle with at least four wheels that used to transport goods which has 3.5 to 7 tons of loads. (Thailand Automotive Institute, 2010)

2. The distance between Physical Resource Management of Chulalongkorn University and Faculty of science, Chulalongkorn University are estimated to be the transportation distance.
3. Raw materials from waste in Chulalongkorn University is assumed that it's not cause environmental impact. Thus, environmental impact from this waste is calculated from the transportation.
4. Processed raw materials is vermicompost which cause environmental impact from the production, so the environmental impacts are calculated from both vermicomposting process and transportation.

3.1.2.2 Life Cycle Inventory (LCI)

LCI shows the material and energy flows (input and output) at every stage of the lifecycle, from organic waste to high quality vermicompost (Kansai and Chaisuwan, 2017), as shown in Figure 6.

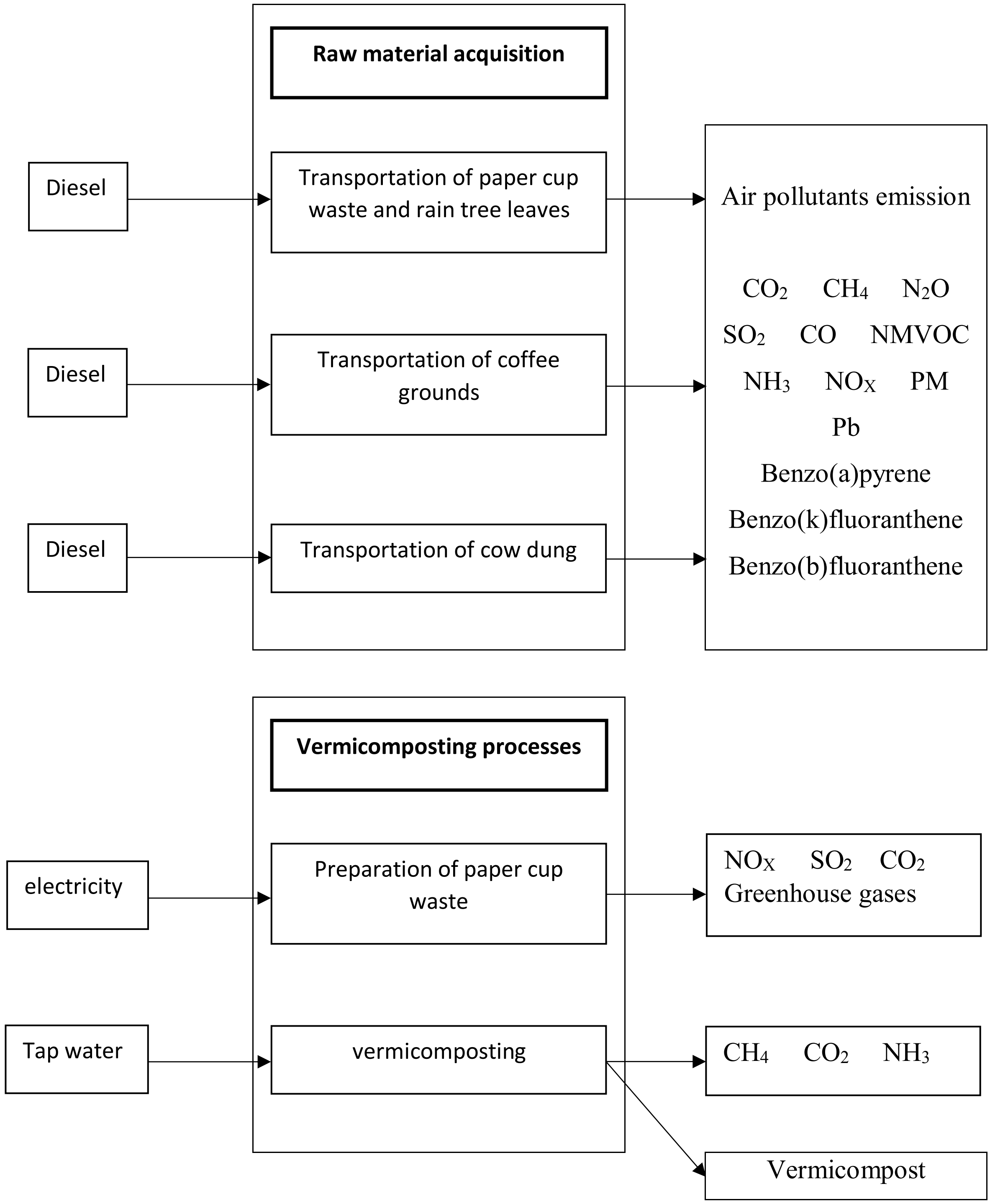

Figure 3.2 Life Cycle Inventory (LCI) of vermicompost

Data calculation

Emission of exhaust pollutants

$$Emission = \Sigma_a[Fuel_a x EF_a] \quad (3.1)$$

Where:

Emission = emission in kg

$Fuel_a$ = fuel consumed (TJ)

EF_a = emission factor (Kg/TJ)

a = type of fuel (e.g. petrol, diesel, natural gas, LPG etc.)

Emission of SO_2

$$E_{SO_2, m} = 2 \text{ x } K_{S, m} \text{ x } FC_m \quad (3.2)$$

Where:

$E_{SO_2, m}$ = emissions of SO_2

$K_{S, m}$ = weight related sulfur content in fuel of type m [g/g fuel]

FC_m = fuel consumption of fuel m [g]

3.1.3 Life Cycle Impact Assessment (LCIA)

The life cycle assessment was analyzed using software SimaPro 8.0 by CML 2 baseline 2000 V2.05 method and used database from National Metal and Materials Technology Center (MTEC), Thai LCI data, IPCC, research paper and other relative journals which the results are expressed in 4 environmental impact categories including abiotic depletion, acidification, eutrophication and global warming.

Due to vermicomposting in all treatments, energy and resources are used in almost every step such as transportation, preparation of raw materials that are paper cup waste and rain tree leaves and vermicomposting process. So, this research study 4 impact categories because there are using natural resource for generate energy and use as transport fuel. For energy generation, it will release 40%, 19% and 56% of greenhouse gases (GHGs), NO_X and SO_2 respectively (Turconi et al., 2013).

Sulfur dioxide (SO_2) and Oxide of nitrogen (NO_X) are gases that affect the environment in terms of acidification and eutrophication. That is, the acidification is caused by SO_2 and NO_X in the atmosphere merging with the falling rain and eutrophication is caused by NO_X and NH_3 (Turconi et al., 2013; Abduli, 2011).

Moreover, global warming or climate change is caused by GHGs including CO_2, CH_4, N_2O etc. that can be generate from fuel combustion and/or respiration.

3.1.4 Interpretation

In this step, the data will be analyzed. The results from software SigmaPro 8.0.5.13 calculation will be shown the comparison of the environmental impacts.

3.2 Ecological Feasibility

An economics analysis of vermicomposting from paper cup waste and rain tree leaves was evaluated using equations 2 and 3.

The break even volume (N*)

$$N * = \frac{F}{P-V} \quad (2)$$

Where:

N* is the break even volume, Unit

F is fixed cost, Baht

P is price per unit, Baht/unit

V is variable cost, Baht/unit

A fixed cost is a cost that does not change in the short term with an increase or decrease in the amount of goods. In this study, fixed costs are machine and equipment costs, including:

1) Shredder

2) pH meter

3) 20-liter plastic container

4) Sieve

A variable cost is an expense that varies with production output. In this study, variable costs are:

1) Raw material capital

2) Transportation capital

3) Human labor

4) Electricity bill

5) Water bill

<u>The payback period</u>

$$\text{Payback period} = \frac{N*}{N} \tag{3}$$

Where:

N* is the break even volume

N is productivity yield/year

Chapter 4

Results and discussion

This research used the Software SimaPro 8.0.5.13 with CML 2 baseline 2000 V2.05, World 1995 method from National Metal and Materials Technology Center (MTEC) to analyze life cycle assessment. The results were separated into 4 impact categories include Global warming (GWP100), Acidification, Eutrophication, Abiotic depletion.

All treatments of vermicompost from Chula Zero Waste paper cup and rain tree leaves are analyzed to compare environmental impact of each treatment.

4.1 The environmental impacts of vermicomposting

The environmental impacts of vermicomposting were calculated and separated into four categories. The results as shown in Table 4.1.

The comparative environmental impacts of vermicomposting of each treatment are shown in Figure 4.1. The explanation of environmental impacts each category as following:

Table 4.1 Environmental impact of vermicomposting of each treatment

Impact category	Unit	T1	T2	T3	T4	T5
Abiotic depletion	kg Sb eq	0.001156	0.001102	0.001047	0.000993	0.000938
Acidification	kg SO2 eq	0.000615	0.000585	0.000554	0.000524	0.000493
Eutrophication	kg PO4--- eq	0.000337	0.00032	0.000303	0.000286	0.00027
Global warming (GWP100)	kg CO2 eq	0.146883	0.139656	0.132429	0.125202	0.117976

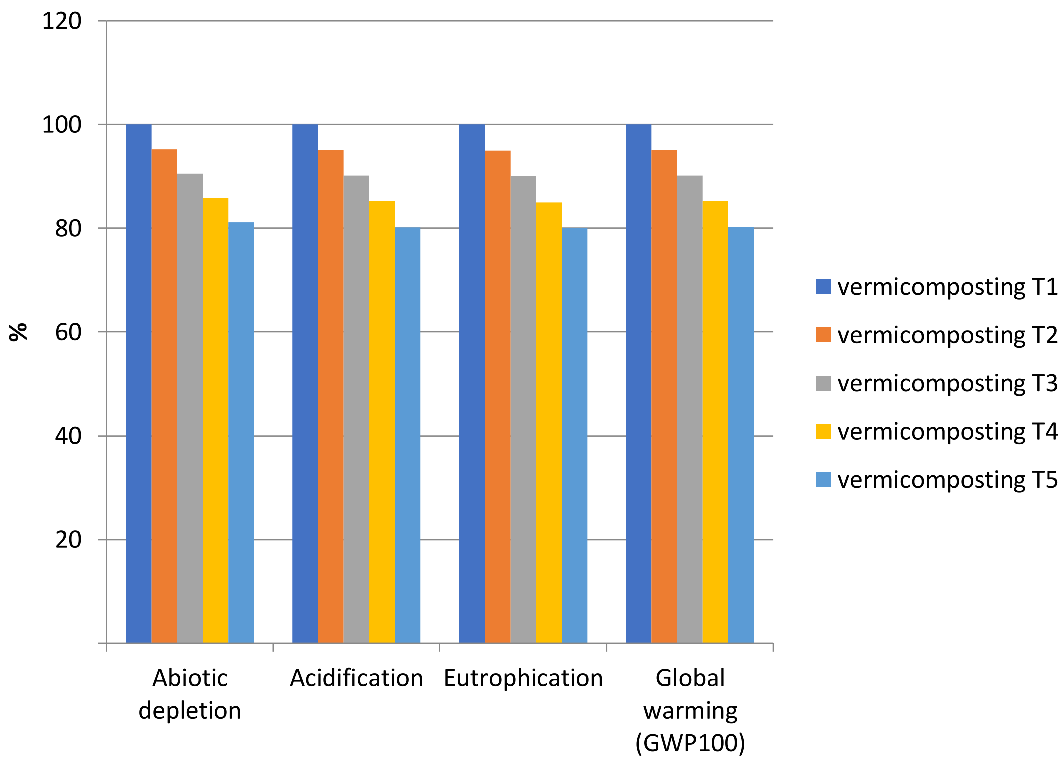

Figure 4.1 The comparative graph of the environmental impacts of vermicomposting of each treatment

The comparison of impact category of all vermicomposting was compared between each treatment using T1 vermicomposting as the most emissions by representative as 100 percent of emissions.

Each treatment of vermicomposting has many processes that cause different impacts consist of raw material acquisition, raw material preparation and vermicomposting process. The impact was calculated and converted into the same factor equivalent which will be the total result of an impact on each category.

The impacts of vermicomposting tend to decrease due to using paper shredder in raw material preparation process is reduce hence it result in lower energy consumption. The shredder uses for cutting the paper cup into 1-5 cm. into vermicomposting process by adding 100, 95, 90, 85, 80 percent of paper cup in T1, T2, T3, T4 and T5 of vermicomposting respectively.

The amount of paper cups and rain tree leaves used in vermicomposting is used to evaluate the environmental impacts. The impacts were caused by the raw material acquisition, raw material preparation which use diesel as fuel for transportation and electricity for cutting paper cups. Moreover, rain tree leaves, coffee grounds and cow dung were used in the vermicomposting process, which requires transportation vehicles that also use diesel as fuel.

4.2 Abiotic depletion impact of each treatment

The comparative abiotic depletion impacts of vermicomposting of each treatment are shown in Figure 4.2 and the result as shown in Table 4.2. The explanation of this impacts as following:

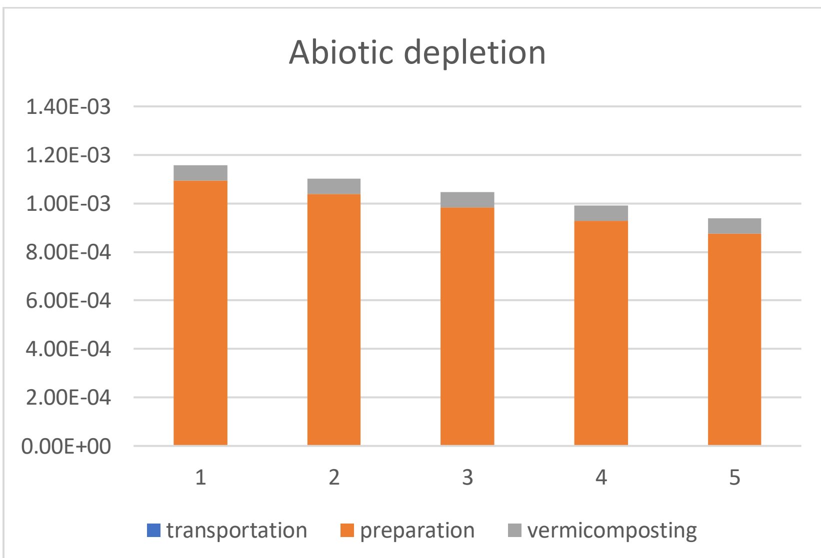

Figure 4.2 Abiotic depletion impact of each treatment of vermicomposting

Table 4.2 Abiotic depletion impact data

Treatment	Unit	Total	Raw material acquisition		vermicomposting
			Transportation	Preparation	
1	kg Sb eq	1.16E-03	2.55E-06	1.09E-03	6.33E-05
2		1.10E-03	2.49E-06	1.04E-03	6.33E-05
3		1.05E-03	2.43E-06	9.81E-04	6.33E-05
4		9.93E-04	2.38E-06	9.27E-04	6.33E-05
5		9.38E-04	2.32E-06	8.72E-04	6.33E-05

Abiotic depletion is caused by the reduction of resources due to resource consumption for various uses include electricity generation, use of fuel for transportation or others. In this result, preparation created the most impact due to the vermicomposting used a lot of paper cup waste. The paper cup waste must be cut into 1-5 cm-piece thus the paper shredder was necessary to help cut paper into piece. The paper shredders use electrical energy, which requires to use natural fuels, resulting in reduced natural resources.

Ministry of Energy (2019) reported in 2019, the production of electricity in Thailand has increased, with the main fuel for electricity production is natural gas and followed by coal/lignite. Natural gas is a nonrenewable resource which 72% of natural gas is supplied in the country (Ministry of Energy, 2019), so using this natural gas may result in the loss of this natural resource in the country.

The abiotic depletion result shown the comparison between all treatment of vermicomposting shown treatment 1 which had the highest of paper cup waste had the highest abiotic depletion impact and treatment 5 which had the lowest of paper cup waste had the lowest abiotic depletion impact. The vermicomposting in treatment 5 to treatment 1 had the impact in range of 9.38E-04 to 1.16E-03 kg Sb eq which used the electricity 88.9, 94.4, 100, 106 and 111 joules per ton in treatment 5, 4, 3, 2 and 1 respectively. When compared with landfilling in Tehran, Iran, it found that the all treatment of vermicomposting consumes less energy than landfilling that use electricity for leachate treatment with the value is 0.139 MJ/ton or 139,000 J/ton (Abduli et al., 2011).

4.3 Acidification impact of each treatment

The comparative acidification impacts of vermicomposting of each treatment are shown in Figure 4.3 and the result as shown in Table 4.3. The explanation of this impacts as following:

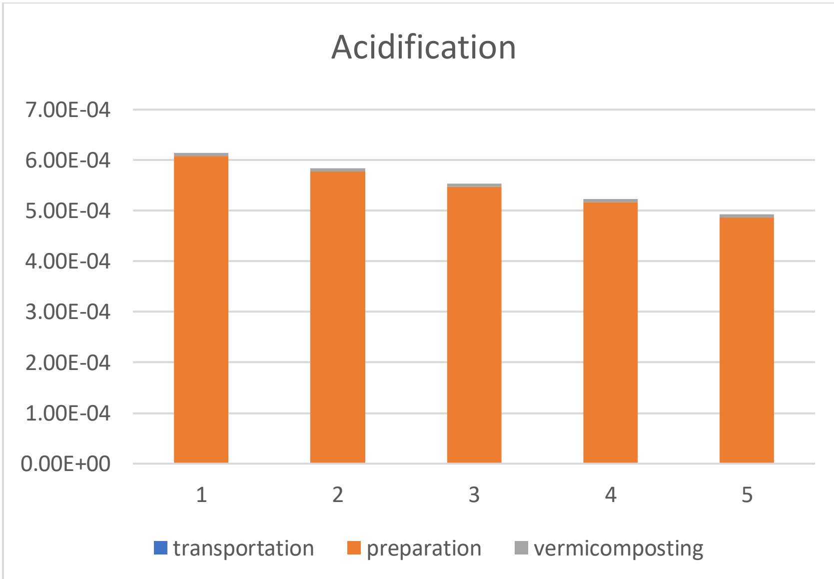

Figure 4.3 Acidification impact of each treatment of vermicomposting

Table 4.3 Acidification impact data

Treatment	Unit	Total	Raw material acquisition		vermicomposting
			Transportation	Preparation	
1	kg SO_2 eq	6.15E-04	7.03E-07	6.08E-04	6.68E-06
2		5.85E-04	6.88E-07	5.77E-04	6.68E-06
3		5.54E-04	4.37E-07	5.47E-04	6.68E-06
4		5.24E-04	6.56E-07	5.16E-04	6.68E-06
5		4.93E-04	6.40E-07	4.86E-04	6.68E-06

Acidification is related to air pollution by S and N such as NH_3, NO_X and SO_X (Aduli et al., 2011; Li et al., 2018). This study found the most cause of impact came from preparation process due to that process used paper shredder which consumed electricity. In term of electricity generation, NO_X and SO_X were emitted into atmosphere with value of 0.01-0.32 kg SO2 eq/MWh (for electricity generation from natural gas, main fuel for generate electricity in Thailand) (Turconi et al., 2013).

In this result, the highest impact was treatment 1 which used paper cup waste as 100% of raw material and the lowest impact was treatment 5. The impact values were 6.15E-04 and 4.93E-04 kg SO2 eq respectively. Not only electricity consumption but also other process could generate NO_X and SO_X but the amount of those pollutants was not large. However, the previous research stated that manage waste by incineration has higher acidification potential than composting with same raw materials.

4.4 Eutrophication impact of each treatment

The comparative eutrophication impacts of vermicomposting of each treatment are shown in Figure 4.4 and the result as shown in Table 4.4. The explanation of this impacts as following:

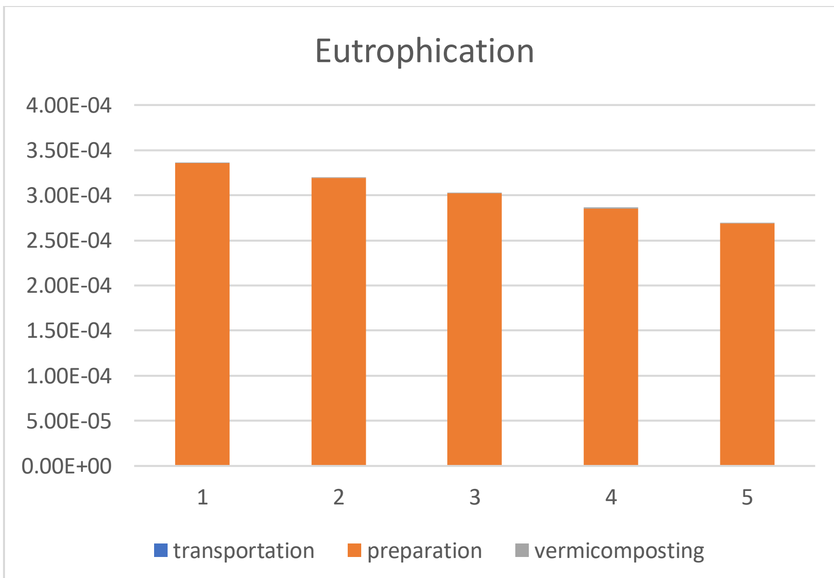

Figure 4.4 Eutrophication impact of each treatment of vermicomposting

Table 4.4 Eutrophication impact data

Treatment	Unit	Total	Raw material acquisition		vermicomposting
			Transportation	Preparation	
1		3.37E-04	1.49E-07	3.36E-04	8.95E-07
2		3.20E-04	1.46E-07	3.19E-04	8.95E-07
3	kg PO_4^{3-} eq	3.03E-04	1.42E-07	3.02E-04	8.95E-07
4		2.86E-04	1.39E-07	2.85E-04	8.95E-07
5		2.70E-04	1.36E-07	2.68E-04	8.95E-07

The causes of eutrophication impact are elements in environment, mainly N and P (nitrogen and phosphorus). Those elements can be transformed to another species composition and produce new biomass in environment (Li et al., 2018).

The result shown the impact that main cause was also raw material preparation process. Although other processes produced air pollution that caused of eutrophication impact (e.g. NO_X in transportation phase, NH_3 in vermicomposting phase) but the use of electricity to prepare the waste had more effect with the greatest impact coming from the treatments with maximum paper cup waste and the least impact from treatments with minimal paper cup waste. That is treatment 1 and 5 respectively. The value of the highest and lowest impact is 3.37E-04 and 2.70E-04 kg PO_4^{3-} eq respectively.

4.5 Global warming impact of each treatment

The comparative global warming impacts of vermicomposting of each treatment are shown in Figure 4.5 and the result as shown in Table 4.5. The explanation of this impacts as following:

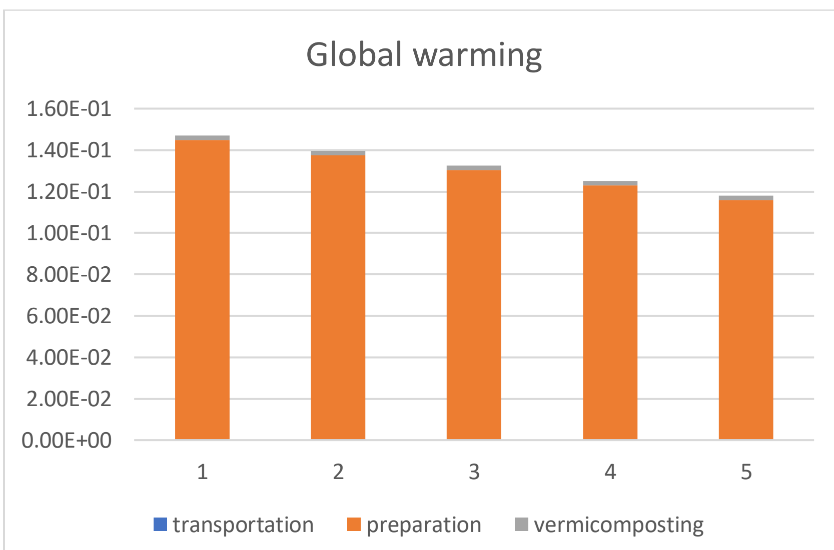

Figure 4.5 Global warming impact of each treatment of vermicomposting

Table 4.5 Global warming impact data

Treatment	Unit	Total	Raw material acquisition		vermicomposting
			Transportation	Preparation	
1		1.47E-01	4.34E-04	1.44E-01	2.11E-03
2		1.40E-01	4.24E-04	1.37E-01	2.11E-03
3	kg CO_2 eq	1.32E-01	4.15E-04	1.30E-01	2.11E-03
4		1.25E-01	4.05E-04	1.23E-01	2.11E-03
5		1.18E-01	3.95E-04	1.15E-01	2.11E-03

Greenhouse gas is gas that can absorb waves and heat radiation. Having a lot of this gas is cause of increasing global temperature. According to Kyoto protocol, there are 6 gases in greenhouse gas group: CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (Thailand Greenhouse gas Management Organization, 2011). There were transportation, preparation and degradation in vermicomposting process, so greenhouse gas was released to the environment. The environmental impact can be assessed for gas emissions by analyzing the effects of global warming potential.

This research showed the global warming impact of all treatments of vermicomposting. The greatest impact was treatment 1 and the least impact was treatment 5 with the value of 1.47E-01 and 1.18E-01 kg CO_2 eq respectively. Every part of vermicomposting could generate greenhouse gas, but the largest effect of this impact came from paper cup waste preparation because of consumption electricity. Thailand generate electricity by natural gas at most and Turconi et al. (2013) reported that the value of impact was in range of 400-900 kg CO_2 eq/MWh, so it affects the environment by releasing carbon dioxide and other greenhouse gases.

When compare the impact between all treatment of vermicomposting in this research and landfilling in research of Abduli et al. (2011), the impact of all treatment of vermicomposting were lower than landfilling which had the value of 3.93 kg CO_2 eq in a same functional unit.

4.6 Economical feasibility of vermicomposting

In this research, the economic feasibility of vermicomposting that have the least environmental impact (Treatment 5) was considered.

4.6.1 Vermicomposting cost

Type		Cost	Source
Waste	Chula Zero Waste paper cup	0 Baht/kg	Physical Resource Management of Chulalongkorn University
	Rain tree leaves	0 Baht/kg	Physical Resource Management of Chulalongkorn University
	Spend coffee ground	0 Baht/kg	Terracotta coffee shop in Chulalongkorn University
Machines	Paper shredder	22,000 Baht/unit	(PSL Star Trading Co. Ltd., 2019: online)

Table 4.6 Distribution of vermicomposting costs

4.6.2 Waste transportation costs

Light commercial vehicle (LCV)

Light Commercial vehicle is a vehicle with at least 4 wheels, used for transporting goods with a weight limit of 3.5-7 tons (Thailand Automotive Institute, 2010). The cost rate of transportation is 16.90 baht/ton in the 3 kilometers transportation which is the distance range between Physical Resource Management of Chulalongkorn University and Faculty of science, Chulalongkorn University (Ministry of Commerce, 2017)

Weight limit of 7,000 kilograms

Transportation cost/round 300 Baht/round

Transportation cost	0.043 Baht/kg

4.6.3 Other transportation cost

The cost rate of transportation is 77.33 baht/ton in the 24 kilometers transportation which is the distance range between earthworm shop and Faculty of science, Chulalongkorn University.

Weight limit of	7,000 kilograms
Transportation cost/round	1,200 Baht/round
Transportation cost	0.171 Baht/kg

List	**Cost**	**Unit**
Fixed Cost (FC)		
1. Paper shredder	22,000	Baht/unit
2. pH meter	2,000	Baht/unit
3. 20-liter Plastic containers	180*500piece	Baht/500unit
4. Sieve	1,500	Baht/unit
Total	115,500	Baht
Variable cost (V)		
1. Raw material capital (Baht/kg)		
1.1 vermicompost quantity	1,000	Kilograms
1.2 Raw material demand		
1.2.1 Chula Zero Waste paper cup	400	Kilograms
1.2.2 Rain tree leaves	100	Kilograms
1.2.3 Coffee ground	225	Kilograms
1.2.4 Cow dung	100	Kilograms

1.2.5 Earthworms	3	Kilograms
1.2.6 Urea	3.175	Kilograms
1.3 Raw material cost		
1.3.1 Chula Zero Waste paper cup	0	Baht/kg
1.3.2 Rain tree leaves	0	Baht/kg
1.3.3 Coffee ground	0	Baht/kg
1.3.4 Cow dung	20	Baht/kg
1.3.5 Earthworms	500	Baht/kg
1.3.6 Urea	12	Baht/kg
Total raw material capital/kg	**3.538**	Baht
2. Transportation capital		
2.1 Transportation cost	0.043	Baht/kg
2.1.1 Total demand of raw materials	728	Kilograms
2.2 vermicomposting quantity	1,000	Kilograms
Total transportation cost	31.304	Baht
Total transportation capital/kg	0.031304	Baht
3. Variable expense		
3.1 Human labor cost (2 persons)	500	Baht/day
3.1.1 Human labor cost/kg	30	Baht
3.2 Electricity cost - From Provincial electricity authority (PEA), 2019	0.529478	Baht/kg
3.3 Tap water cost - From Provincial waterworks authority (PWA), 2019	1.5	Baht/kg
3.4 vermicomposting quantity	1,000	Kilograms

Total variable expense	32.03	Baht
Average variable cost (AVC)	35.60	Baht
Productivity/year (N)		
Working day	248	Day/year
Productivity	16.67	Kg/day
Number (N)	4,134.16	kg/year
Price (P)		
vermicompost cost	45	Baht/kg

The breakeven volume: N* (Pieces)

$$N^* = \frac{F}{P-V}$$

$$= \frac{115,500}{45-35.60} = 12,287.23 \text{ kg}$$

The payback period (Years)

$$\text{Payback period} = \frac{N^*}{N}$$

$$= \frac{12,287.23}{4,134.16} = 2.97 \text{ (2 years 11 months 20 days)}$$

Chapter 5
Conclusion

5.1 Conclusion

This study used the Life Cycle Assessment methodology to carry out an environmental assessment of vermicomposting from paper cup waste and rain tree leaves in Chulalongkorn University that covered from raw material acquisition to vermicomposting process. The environmental impact of vermicompost depends on the raw material preparation process. Emissions to the environment are mainly caused by energy consumption which is electricity. The pollutants are CO_2, N_2O, SO_2, CO, NH_3, NO_X, PM and other greenhouse gases that release from power plant.

Comparison result shows that the vermicomposting in treatment 5 which consist of 80% of the paper cup waste and 20% of rain tree leaves has the lowest environmental impact due to this treatment use the least amount of paper cup waste so this treatment use the least energy consumption for preparing paper cup waste with suitable size for vermicomposting.

On the other hand, vermicomposting in treatment 1 has the highest environmental impact because use the large amount of paper cup waste that uses a lot of energy to prepare.

To evaluate economic feasibility, vermicomposting in treatment 5 which is the best vermicomposting in LCA study can recycle waste in Chulalongkorn University, but it spent quite a long time to payback. In this regard, waste management in Chulalongkorn University by vermicomposting may be developed and further studied to reduce costs and further increase value in the future.

5.2 Recommendations

The raw material preparation process in this research has used a lot of energy-consuming tools. Changing the method of material preparation may help to reduce energy consumption. For example, use the other machine which use less electricity or use labors to prepare materials, which reduces the restrictions on composting. Furthermore, changing the preparing method from using machine to using labors can reduce electricity cost and machine cost.

To reduce the pollution from transportation, vermicomposting should do at the place nearby the waste collection site. This way can also reduce transportation cost. Or another way is building the vermicomposting house not only reduce vermicomposting container cost but also save space.

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