LIFE CYCLE ASSESSMENT OF SOLID WASTE MANAGEMENT IN PARO DISTRICT, BHUTAN

BY

CHONI ZANGMO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)
SIRINDORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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A Thesis presented

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Choni Zangmo

Submitted to
Sirindhorn International Institute of Technology
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DECEMBER 2017

Abstract

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by

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In numerous studies, Life Cycle Assessment (LCA) tool has been utilized for effective municipal waste management in various countries to assess waste treatment technologies and strategies. Eventually, the waste is utilized as a resource that could promote sustainable societies in most of the developed countries. However, research on environment impact assessment of current solid waste management in developing countries is inadequate. Paro district is one of the most famous destinations for tourist in Bhutan, the least developed country where solid waste management issue has turned out to be extreme, driven by an increase in population, changes in utilization style, increase in tourism, and growth in GDP. Accessibility of reliable data on solid waste, and study on environmental impact assessment of present solid waste management system in the Paro district is very little. The essential target of this thesis is to identify the current situation of solid waste management practices in Paro district of Bhutan.

Characterization and analysis of solid waste composite were carried out to identify the waste composition and generation in household and hotel sectors. Contrast situations or scenarios were developed to discover the suitable techniques and to take care of environmental burden of current solid waste management system in the study area. Basically, in the current solid waste management situation, there is no waste segregation at source due to lack of awareness and open dumping/open landfilling without any waste treatment after collection due to lack of infrastructure, budget, policy and feasible framework.

LCA SimaPro8.3 software and CML2 Baseline 2000 impact assessment methodology was used for the interpretation and comparison of alternative scenarios detailed with reference to some significant categories of environmental effect like Global Warming Potential (GWP), Ozone Layer Depletion Potential (ODP), Human Toxicity Potential (HTP), Photochemical Oxidation (PO), Acidification Potential (AP) and Eutrophication Potential (EUP) and Abiotic Depletion Potential (ADP). The alternative waste treatment scenarios consist of Scenario-0 (100% landfill), Scenario-1 (composting 50% of food waste), Scenario-2 (recycling 50% of recyclable waste), Scenario-3 (recycling 25% of recyclable waste and composting 25% of food waste), and Scenario-4 (recycling 50% of recyclable waste and composting 50% of food waste).

Scenario-4 (recycling 50% of recyclable waste and composting 50% of food waste) was recommended as the most environmentally effective waste management option where most of the environmental impact categories are relatively low. The results also demonstrated that the most environmentally efficient way to manage municipal solid waste is the combination of recycling and composting scenarios. Even more particularly, Paro district would be vastly improved served establishing a composting plant for organic waste and expanding recycling activities. Further achievement of the successful result of selecting above scenario will be fulfilled by developing various waste management programs with the end goal to reduce the environmental impact, to minimize the waste in the landfill and to increase the economic growth of the country.

Keywords: Solid waste management, Paro district, life cycle assessment, inventory analysis, SimaPro8.3, CML2 baseline 2000 method, environmental impact category, scenarios.

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My heartfelt thankfulness goes to Sirindhorn International Institute of Technology (SIIT) for providing the full budgetary help that subsidized part of the exploration discussed about in this thesis and to every one of the staffs of SIIT for the overwhelming hospitality. Furthermore, I would like to thank the “Druk Waste Collection” a private organization for providing the required records and conceding me the authorization to carry out waste analysis and characterization in the dumping site and allowing me to conduct a questionnaire interview.

Last but not the least, I especially would like to thank my family for continually supporting and having faith in me.

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List of Acronyms and Abbreviations

GNI	Gross National Income
GNH	Gross National Happiness
USEPA	United States Environmental Protection Agency
MMTCE	Million Metric Tons Carbon Equivalents
EPA	Environmental Protection Agency
LCA	Life Cycle Assessment
LCI	Life Cycle Impact
LCIA	Life Cycle Impact Analysis
AP	Acidification Potential
ADP	Abiotic Depletion Potential
GWP	Global Warming Potential
EUP	Eutrophication Potential
HTP	Human Toxicity Potential
ODP	Ozone Layer Depletion Potential
PO	Photochemical Oxidation
POCP	Photochemical Ozone Creation Potential
GLO	Global
RoW	Rest-of-the-World
CFCs	Chlorofluorocarbons (CFCs)
HCFCs	Chlorofluorocarbons (HCFCs)

Chapter 1

Introduction

1.1 Background

Waste management challenges clearly emerge from the way that it is a between disciplinary and exceptionally complex issue. All through the history of World War II, improvement of worldwide waste management framework confronted the extreme environmental issues in most of the nations. Impacts include such as human health damages, depletion of resources, ecosystem damages and climate changes because of greenhouse gas emissions (GHGs) from landfills, contact with harmful chemicals and particles during waste collection and treatment, outflows of heavy metals to the surrounding site due to inadequate recycling frameworks (Laurent et al., 2014). The current global annual costs of solid waste management is 205.4 billion US dollar and it is predicted to be increase to 375.5 billion US dollar in 2025 (Sadef et al., 2016). Due to fast development in populace, financial advancement and change in style for everyday comforts, tons and tons of waste, including both hazardous and nonhazardous waste is produced from hospital, household, research laboratory, restaurants, hotels and other industries. In no time, the volume of waste generated all around the world was estimated around 1.3 billion tons in 2012 (1.2 kg/capita/day) and predicted to achieve 2.2 billion tons for consistently by 2025 (Monteiro and Freire, 2012).

The quantity of municipal solid waste (MSW) produced relies on various variables, for example, sustenance propensities, the way of life style, the level of business exercises and seasons (Sharholy et al., 2008). Developed countries generate huge amount of solid waste per capita while developing nations produce less amount and utilized less amount of solid waste due to lack of treatment technique (Cairncross and Feachem, 1993). Apparently, the waste generation in urban districts has impact the balance of environmental pollution against the natural resources (Kollikkathara et al., 2009) since it includes diverse associated issues and should accomplish destinations which are frequently in strife (Caruso et al., 1993). When the solid waste is managed properly, it can reduce impacts on human health and environment. However, improper handling of waste may lead to environmental contamination and health problem (McDougall et al., 2008).

Yang et al. (2008) demonstrated that the nonstop utilization of important space for uncontrolled landfills as well as the poor waste management framework makes critical dangers to human wellbeing (Yang et al., 2008). In developed country like Germany, the use of landfill has been banned since the 1990s and increase the rate of recycling and composting (Burnley, 2001). However, landfills have been to a great extent depicted as the easiest, effective and the most broadly utilized as waste disposal method in developing countries (Owusu et al., 2012). Food waste adds to abundance utilization of freshwater and petroleum derivatives which impacts worldwide climate change due to CH_4 and CO_2 emissions from the food decomposition (Hall et al., 2009). Generally, food waste is generated from various sources such as household, shops, hotels, markets, restaurants and institutes. The food waste generated per capita in Sub-Saharan Africa and South/Southeast Asia is 120 to 170 kg/year while generation of food waste in Europe and North-America is 280-300 kg/year (Song et al., 2015). Adhikari et al. (2006) stated that generation of food waste is related to two factors, that is gross national income (GNI) and the population (Adhikari et al., 2006).

Papargyropoulou et al. (2014) reported that the most appropriate choice for the prevention and management of food waste is by examining the food supply chain and proposing a framework (Papargyropoulou et al., 2014). The composting method is one of the approach to diminish the amount of organic waste going to the waste stream (Adhikari et al., 2010). However, due to poor quality of plant, unsegregated materials and production of high concentrations of heavy metal in compost contaminated soil is very common in many developed countries (Taiwo, 2011). On the other hand, Cheng and Hu (2010) claimed that composting requires more space when compared to other waste management technologies and may pollute soil producing heavy metals and pathogens (Cheng and Hu, 2010). In the recent years, various investigations have been published on environmental impact assessment of different municipal solid waste management scenarios (Fernández-Nava et al., 2014).

In context, many countries have paid high attention to municipal solid waste management issues to have a better comprehensive solution and be able to perform it in an environmentally sound manner. However, some of the developing countries do not have this understanding including Bhutan. Bhutan is not any more a disconnected economy; over the span recently years of advancement, Bhutan has had real correspondence with rest of the world to enhance developing plans which demonstrates that Bhutan has been subjected to the ecological effects from developing plans like other countries (Uddin et al., 2007). Bhutan is a tiny mountainous country sandwiched between the most populated countries, China and India to the North and South respectively with 38,394 sq.km of total land territory which is nearly the same size of Switzerland (Tobgay et al., 2011).

In the world happiness literature, Bhutan is most popular for its objective of promoting Gross National Happiness (GNH) by which the personal satisfaction is comprehended comprehensively, surpassing financial prosperity as it would be measured by per capita Gross Domestic Product (GDP), and surpassing subjective prosperity (Ura et al., 2012). The number of inhabitants in Bhutan is only 0.78 million and total national salary per capita is US$ 2,719 (NSB, 2015). In 1960s, Bhutan's economy started to modernized with the foundation of fundamental framework, for example, electricity, road, broadcast communications, and transport (Whalley, 2004). Urbanization is increasing at a normal of 7% every year and it was predicted that more than 50% of populace will dwell in urban zones by 2020 (Halcrow et al., 2014). In spite of the fact that Bhutan is as yet one of the world's least developing nations, its economy has developed quickly amid the previous two decades, causing tons of solid waste generation every year. Furthermore, Bhutan lack reliable data on solid waste quantity, characterization and management.

The first ever research on solid waste was held in 2007 for 10 urban areas and it was estimated that 43,700 tons of municipal solid waste have been generated from the urban areas of Bhutan with 0.53 kg of waste per person in a day (Phuntsho et al., 2010). Solid waste dumping in the landfill is yet a typical waste management strategy in Bhutan since it is financially savvy and basic, not at all like other waste management techniques which are expensive and requires innovative specialists to work it. The major factors of inadequate waste management in Bhutan are due to changes in consumption pattern, open dumping, rural-urban migration, insufficient waste collection services, insufficient policy and framework (RSPN, 2015).

Despite various attempts in issuing solid waste management legislation, the country is still cannot tackle the problem effectively. The government of Bhutan banned utilizing plastic bags and importing second hand products like computer, printers and other electronic materials in 1999, however, there has been drastically change in utilization style from local organic to imported package food (Phuntsho et al., 2010). In 2007, the Royal government of Bhutan established new waste management initiatives, however they increased little improvement (Allison, 2014). In parallel in 2012, national regulations were presented under the Waste Prevention and Management Act 2009 that provided solid waste management system and implementation (Halcrow et al., 2014). Legislature of authorities revealed trouble in imparting "civic sense" to motivate citizen who are responsible for the waste generation and littering.

In numerous studies, solid waste is well studied and well utilized as a resource that could promote sustainable societies in most of the developed countries. However, proper solid waste management in developing country like Bhutan is inadequate. This insufficiency strategies in the waste management system are the consequence of deficient money related assets, lacking information, and technical specialized and experts of authorities to improve the management system. Furthermore, finding adequate procedures to adapt to waste management issues is turning into a very hard undertaking, inferable from the expanding attention to ecological issues by populace and responsible authorities. The capability and flexibility to take any account of expensive treatment plants are not the option for Bhutan.

This study is coordinated towards understanding one of the principle parts of sustainable waste management framework that is environmentally effective with the goal to propose an appropriate approach or intercession for better solid waste management in Paro district.

1.2 Objectives

1. To compile baseline data and determine the issues and challenges faced by the local people, hoteliers, and the waste collection agencies in Paro district, Bhutan
2. To identify environmental impacts arising from increasing MSW using Life Cycle Assessment (LCA) tool.
3. To recommend environmental impact reduction scenarios as a contrasting option to the present waste management system.

1.3 Scope of the study

1. Paro of Bhutan was selected as a study area.
2. Primary and secondary data were collected from the stakeholders such as government and private organization to understand the waste generation, composition and existing waste management system in Paro.
3. Environmental impact analysis of various waste management scenarios using LCA software called SimaPro8.3 and CML 2 baseline method.
4. Environmental impact categories include: Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Photochemical Oxidation (PO), Acidification Potential (AP), Ozone Layer Depletion Potential (ODP) and Eutrophication Potential (EUP) from the current waste management scenario (landfill) will be estimated using a comparative life cycle assessment approach.
5. This study will make a systematic analysis of current waste management from the study area and highlight some method to improve by developing different waste treatment scenarios such as recycling and composting.

Chapter 2

Literature Review

This chapter has six broad sections with the discussion about the solid waste characterization and waste composition in Asian countries, the concept of waste management system, factors influencing solid waste management system, solid waste management system in Bhutan, and finally the life cycle assessment of solid waste management system.

2.1 Overview of solid waste

Waste is considered as substance or objects which are discarded or proposed to be discarded or require to be discarded (Sasikumar and Krishna, 2009). Solid waste is characterized as any useless, undesirable, or disposed of material without any free flowing fluid substance based on the United States Environmental Protection Agency (USEPA) (Omuta, 1987). All domestic refuse and non-hazardous wastes such as street sweepings and construction, business and institutional waste produced from the local community are called municipal solid waste (Simões et al., 2011). Definition of MSW in the UK is based on waste collection system instead of its composition and the source of generation (Burnley, 2001). Sources of solid waste are raw materials called mining waste, manufacturing called industrial waste and consumer called municipal and agricultural waste. In general, solid waste can be constituents of various categories (Hamer, 2003):

- Non-biodegradable inorganic waste;
- Unmanageable synthetic organic waste;
- Biodegradable natural organic waste;
- Off-particular and fire-and water-harmed chemicals of obscure structure and qualities;
- Hazardous organic mixes;
- Metals, metalloids and their subordinates;
- Somewhat biodegradable characteristic organic waste

In Bhutan, according to "Waste Prevention and Management Regulation, 2012", solid waste is categorized into 4 major groups:

- Medical waste;
- Municipal waste;
- Industrial waste;
- E-waste

The most astounding contribution of municipal solid waste is from the household waste category when it is compared with other sources, comprising 70% to 80% recyclables of aggregate composite solid waste in the landfills (Moh and Manaf, 2014). This municipal solid waste can be both hazardous and nonhazardous waste. Hazardous wastes can be like plant pesticides, pharmaceuticals, photographic chemicals, certain cleaning agents, cleanser things, fluorescent tubes, squander oil, heavy metal-containing batteries, wood treated with harmful substances, electronic and electrical waste and disposed of CFC-containing items. Some of the general types of waste from different sources are shown in Table 2.1.

Table 2.1 Types of municipal solid waste

Sources	Typical waste generator	Types of solid waste
Residential	Single and multifamily households	Organic waste like food and garden waste, paper, cardboard, plastics, textiles, glass, metals, ashes, other wastes such as bulky items, electronics, batteries, oil and tires and household hazardous wastes
Business	Shopping stores, hotels, restaurants, markets, office buildings	Paper, food, cardboard, plastics, wood glass, metals, bulky wastes, hazardous wastes
Institutional	Schools, government center, hospitals, prisons	Paper, cardboard, plastics, wood, food wastes, garden waste, glass, metals, bulky wastes, hazardous wastes
Municipal services	Road cleaning, finishing, parks, shorelines, recreational regions	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches and other recreational areas

Source: Simões et al. (2011)

2.2 Waste composition in Asian countries

The composition of MSW changes as per the social culture and monetary status of the inhabitants, urban structure, a density of populace, degree of business movement and climate (Talyan et al., 2008). Notwithstanding, a couple of authorities stated that highly paid family units produce more inorganic material from the waste packaging, while degradable organic waste issue is high in those family units that have low income (Zurbrugg, 2003). Example: Table 2.2 shows that an organic waste generated in developed countries like Japan and South Korea is low when it is compared with other Asian developing countries.

Table 2.2 Waste composition in Asian countries

Country	**Types (%)**					
	Organic waste	**Paper**	**Plastic**	**Glass**	**Metal**	**Others**
Malaysia[3]	45.0	7.0	24.0	3.0	6.0	15.0
Singapore[2]	44.4	28.3	11.8	4.1	4.8	6.6
Thailand[2]	48.6	14.61	13.9	5.1	3.6	14.2
China[2]	35.8	3.7	3.8	2.0	0.3	54.3
Hong Kong[2]	37.2	21.6	15.7	3.9	3.9	17.6
Indonesia[2]	70.2	10.9	8.7	1.7	1.8	6.2
Japan[2]	17.0	40.0	20.0	10.0	6.0	7.0
Laos[2]	54.3	3.3	7.8	8.5	3.8	22.5
Myanmar[2]	80.0	4.0	2.0	0.0	0.0	14.0
South Korea[2]	31.0	27.0	6.0	5.0	7.0	23.0
Philippines[1]	50.0	12.0	25.0	3.0	5.0	5.0

Sources: [1](ADB, 2013), [2](Mendes MR, 2004) and [3](Agamuthu, 2011)

Improper management of MSW can bring unfavorable environmental effects, the general health hazard, and other financial issues (Stoykova, 2010) and (Jolliet et al., 2003) due to large quantity of waste generated with different characteristics of impact potential as shown in Table 2.3.

Table 2.3 Potential impact from waste characteristics

Characteristic	Main potential burden
Moisture	Size, shape, hardness, thickness, quality, and so forth may have basic effect on fuel demand, in like manner potential for litter, tidy, noise during unit operation.
Biodegradability	Low values and high values biodegradability may increase litter potential and leachate levels respectively.
Combustibility	Will thermally degrade making comparable weights to ignitable waste, for example, smell, gas outflow and leachate discharges.
Chemical reactivity	Reaction products on blending with other wastes, reagents or exposure to air/water may lead to burdens to all media. May also create burdens if subject to thermal process making comparable weights to ignitable waste.
Toxicity	Waste material containing toxic elements or compounds present have potential discharge to condition influences burden and increases level of burden.
Leachability	Nature of solvent parts influences burden and level of burdens.
Sterility	Potential of human health impact due to waste exposure.
Volatility	May create odor, fire/explosion risk and health risks potential during storage.
Flammability	During storage and physical processes that generate heat/sparks may causes fire/explosion risk.

Source: (Menoufi, 2011)

High concentration of toxic components in hazardous waste prompts polluting the surface and groundwater through the leachate accumulation from the dumping sites (Pappu et al., 2007).

2.3 General concepts of Municipal Solid Waste Management (MSWM)

A major issues in urban areas of developing countries is in terms of MSW management due to rapidly developing urban communities and towns (Rebitzer et al., 2004; Kumar et al., 2009). To build up an appropriate waste management framework, estimation of quantity and quality of waste generation, the accessibility of resources and the ecological status of a specific society are vital (Menoufi, 2011). Furthermore, comprehensive updated solid waste management framework is essential to suit the amount of waste generated, and characterization of waste quality (Pant et al., 2010). MSWM incorporates exercises associated with waste generation, storage, collection system, transportation to transfer site, waste treatment process and disposal of solid waste.

2.3.1 Solid waste generation

The fundamental parameters influencing the yearly amount generation and composition of the municipal solid waste are: 1) Population: the more individuals living in a nation, the more waste generation and 2) Mean living standard of the nation: the capacity of the populace to consume goods and products (Daskalopoulos et al., 1998). Similarly, Sharholy et al. (2008) stated that the amount of MSW produced relies upon various variables such as lifestyle, food habits, season and level of commercial activities (Sharholy et al., 2008). In context, solid waste generation varies from one country to another country due to many factors such as population, GDP, climate, tourism activity shown in Table 2.4.

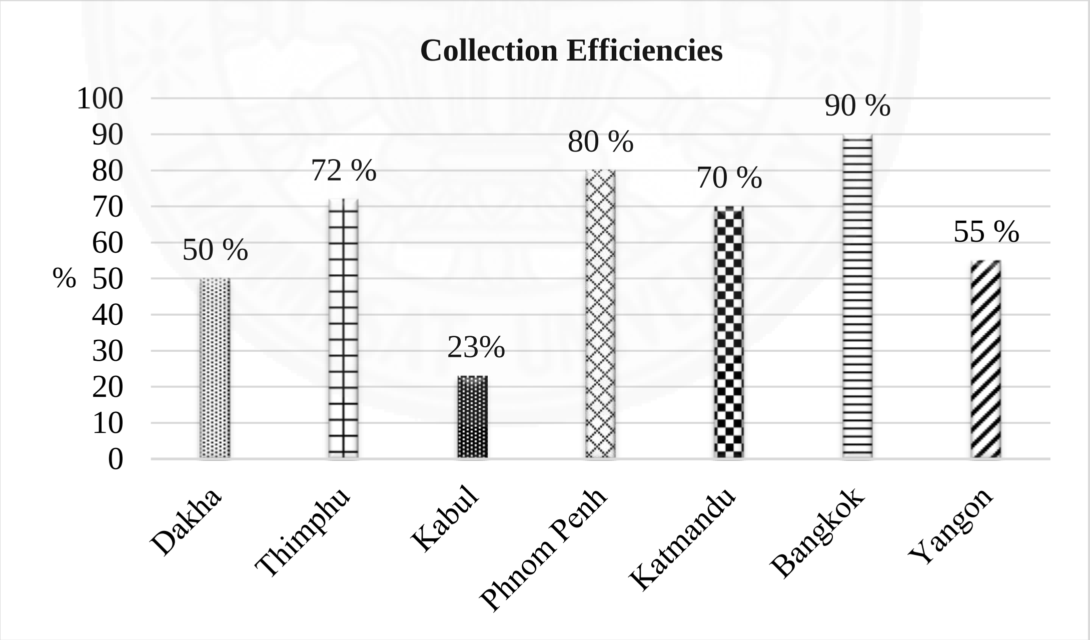
Table 2.4 Key reasons of solid waste generation

Country	Waste generated (kg/capita/day)	Key reasons	Sources
Nepal	0.66	Increasing urbanization	(Dangi et al., 2011)
Maldives	2.5	Tourism activity	(UNEP, 2002)
Kuala Lumpur	1.90	Population growth and business activities	(Saeed et al., 2009)
China	0.98	Urbanization, population growth and industrialization	(Zhang et al., 2010)
Nigeria	0.44 to 0.66	Population growth	(Ogwueleka, 2009)
Mexico	1.45	Population growth	(Gómez et al., 2009)

The waste generation also varies within the country which is mainly associated to family structures, consumption patterns, and life style where a few authors expressed that solitary families deliver more waste per capita than families.

2.3.2 Solid waste collection and transportation

Collection and transportation are the most essential and expensive part of the procedure in view of man power of the work and the massive utilization of vehicles in the collection and transportation process (Amponsah and Salhi, 2004). MSW is collected by utilizing different sorts of vehicles relying upon the diverse sorts of collection bins and the road widths (Chiplunkar et al., 1981). For instance, Medina and Dows (2000) reported that most of the developing countries uses two types of communal bins called fixed bins and movable bins and collect only 50% to 80% of waste generated and dump in the open area (Medina and Dows, 2000). The waste collection frequency varies from place to place in developing countries (shown in Figure 2.1); at the center zones and business zones waste is collected every day while in the low populace thickness ranges and neighborhoods waste is collected after two to three days (Glawe et al., 2005). Collection efficiencies in some of the capital city of developing countries are shown in Figure 2.1 including the capital city of Bhutan.



Source: Glawe et al. (2005)

Figure 2.1 Comparison of waste collection efficiencies

To increase the percentage of collection efficiency, waste separation at source should be practiced which is inadequate in most of the developing countries.

2.3.3 Waste treatment methods

There are three groups of waste treatment technique such as physical, biological and thermal treatment. Physical and biological involves 3Rs, composting and anaerobic digestion. Thermal technological method includes pyrolysis, gasification and incineration for converting energy from waste which are more feasible procedures and cautious of human prosperity and the environment. Developed country like US produces tons of waste and also utilized 90-95% of generated waste effectively for energy production at treatment plants (Sudhir et al., 1996). There are different kinds of waste treatment options as shown in Figure 2.2.

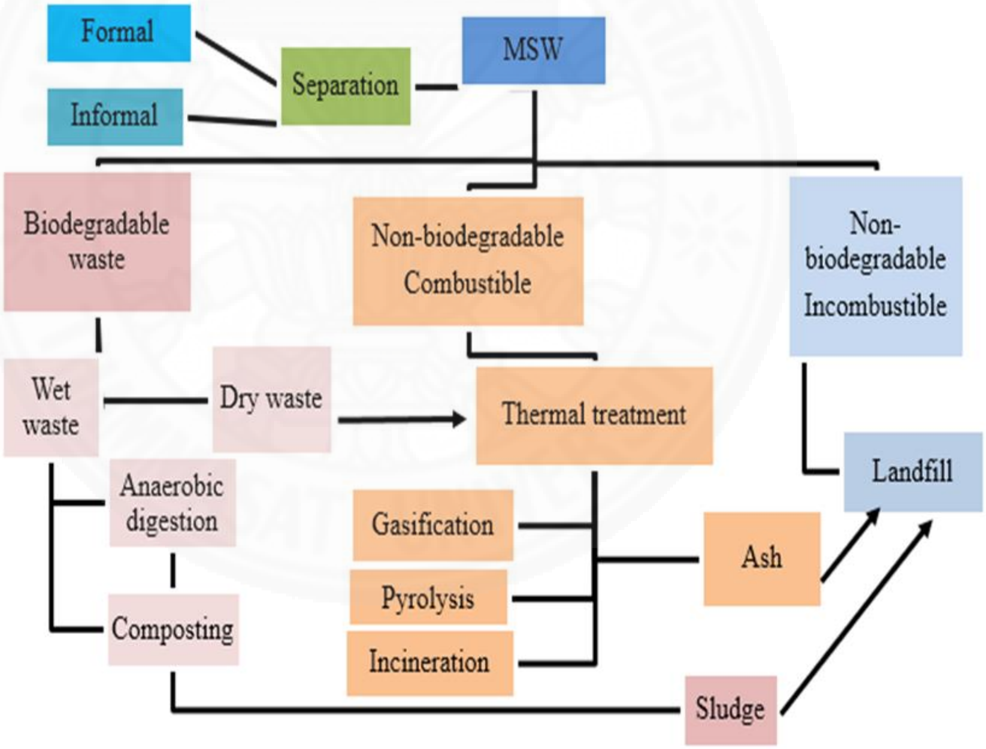
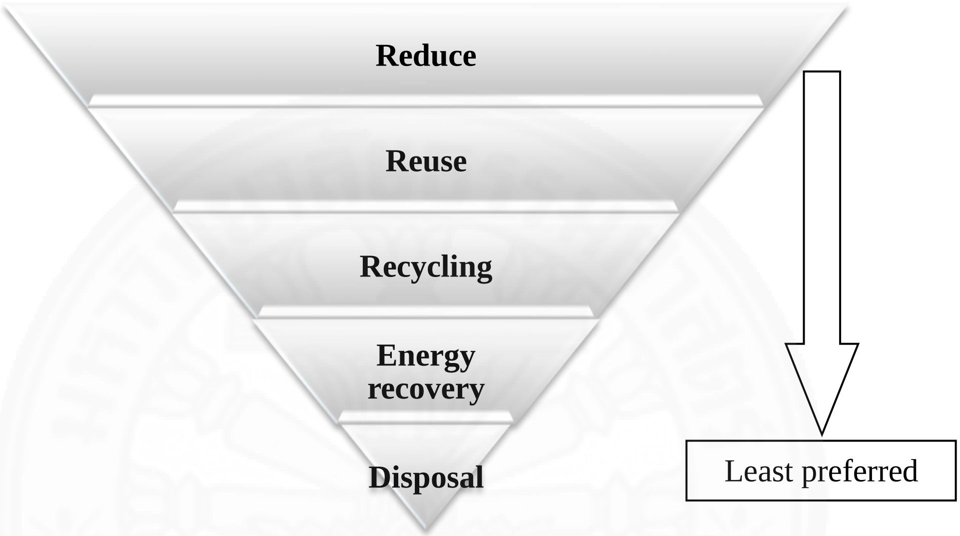


Figure 2.2 Waste treatment options

2.3.3.1 Reduce, Reuse and Recycle (3Rs Approach)

The importance of waste hierarchy remains the foundation of most waste minimization methodologies (Demirbas, 2011). The primary idea for the waste handling hierarchy was first borne out of the Dutch government's insufficiency of landfill areas (Wolsink, 2010). The solid waste hierarchy is a universally acknowledged and highly recommended ranked preferred to handle waste using the following descending order of preference: reduce, reuse, recycling, energy recovery and disposal as shown in Figure 2.3.



Source: (Papargyropoulou et al., 2014)

Figure 2.3 Waste management hierarchy

Recycling is constantly set above disposal in the waste management hierarchy because it achieves a major diminished in the yearly budget of solid waste management, and furthermore an extension in the life of the landfill (Diamadopoulos et al., 1995). Furthermore, recycling waste is one of the solutions to overcome problems associated with overloaded landfills (Guerrero et al., 2013). As far as recycling waste, industrialized nations, for example, Germany, Sweden, Japan and the United States have as of now accomplished noteworthy outcomes in exhaustive usage of resources and solid waste management (Hui et al., 2006). Through utilizing approaches and techniques, developed countries have thoroughly applied the waste management hierarchy principles inside an extensive structure of integrated solid waste management systems (Achankeng, 2004). To help lessening of waste and move towards more economical asset utilization, the US Environmental Protection Agency

(US EPA) built up the Resource Conservation Challenge (RCC) in 2002 and the primary focus of RCC is to help groups, industries, and the general population giving for importance on waste management instead of disposing it (Thorneloe et al., 2007).

For developing nations, recycling and recovery are generally led by informal sector on all levels of the waste management stream. There are many factors affecting sustainable recycling of municipal solid waste management in developing countries as shown in Table 2.5. Some of the factors that have high impacts on recycling are due to lack of education on solid waste management (83%), inadequate waste segregation and collection (79%) and lack of budget from the government sector (77%).

Table 2.5 Factors affecting sustainable recycling of MSWM in developing countries

Title	Description	Percent of case studies as an obstruction
MSWM personnel education	Professionally skilled and extensively trained laborers in the positions of MSWM	83
Waste segregation and collection	Presence and viability of private or government waste collection, segregation of waste by scavengers, the municipality, or temporary workers of private organization	79
Government finances	Operating expenditure, assigning spending plan to MSWM and steadiness and reliability of funds	77
Education level of household	Level of learning on waste management techniques and understanding association between human conduct, waste taking care of and environment or health or sanitation inside family units	69
Waste characterization	Evaluation of waste generation, composition and recovery/recycling rates of waste stream	67
Government legislation/policy	Presence of regulations, authorization of laws, and utilization incentive schemes/plans	63
Technologies and human resources	Accessibility and powerful utilization of innovation or potentiality of human workforce and considering the safety of technologies	58

Title	Description	Percent of case studies as an obstruction
MSWM plan	Presence and viability of an integrative, extensive, long-term methodes for MSWM.	50
MSWM administration	Presence and effectiveness of private and/or public management of waste collection, transportation recovery, and disposal	44
Local recycled-material market	Presence and profitability of market frameworks depending on recycled material throughout, association of private businesses, middlemen, and large industries/exporters	36
Household economics/income	People's wage impacting attitude of waste handling such as reuse, recycling, illegal dumping, waste collection /transfer charges and readiness to pay by residents	22
Land accessibility	Land characteristics, for example, territory, proprietorship, and advancement directing MSWM	0

Source: (Troschinetz and Mihelcic, 2009)

Non-recycling material has a special kind of treatment technologies for conversion of waste to energy such as incineration, pyrolysis, gasification, composting and anaerobic digestion (Murphy and McKeogh, 2004).

2.3.3.2 Composting

Organic waste is one the major waste fraction based on country's GDP which represents 20% to 80 % of the municipal solid waste principle stream (Adhikari et al., 2009; Papadopoulos et al., 2009). Organic waste disposed in the landfill releases greenhouse gasses which can be recovered at a cost, treatment of leachate produced and expels land which generally could be utilized for other purposes (Adhikari et al., 2010). One of the widespread biological methodology used for the treatment of organic waste is composting because it is a low cost technology (He et al., 1992). Furthermore, it creates job opportunity for people, reduce poverty and improve economic development through production of bio fertilizer. However, CH_4 and N_2O can be produced due to inadequate management facility and the development of semiaerobic or anaerobic conditions during composting and mechanical biological treatment (Menikpura et al., 2013).

Therefore, Narayana (2009) concluded that segregating of waste before composting is the best choice to deal with organic waste management in developing countries (Narayana, 2009). Though composting method is the best option for the reduction of organic waste, it was demonstrated that composting method can cause environmental impact if their by-products are not appropriately used as planned (Kim and Kim, 2010). There are different techniques accessible for the organic waste treatment, however, anaerobic digestion has all the earmarks of being a promising methodology (Lee et al., 2009).

2.3.3.3 Anaerobic digestion

Dhar et al. (2016) stated that an anaerobic digestion is more suitable for the industrial and agricultural wastes because they contain a large amount of effortlessly biodegradable materials (Dhar et al., 2016). Anaerobic digestion produces biogas and bio fertilizer and at the same time diminish the ecological contamination (Khalid et al., 2011). Generally, biogas composed of 48–65% methane, 36–41% carbon dioxide, up to 17% nitrogen, less than 1% oxygen, 32–169 ppm hydrogen sulfide and hints of different gasses (Ward et al., 2008). Methane is the significant part of the biogas utilized as a part of numerous homes for cooking and heating (Demirbas, 2011). Furthermore, it was claimed that from the application of anaerobic digestion scheme, potential effects, for example, Global warming, Acidification, Stratospheric ozone depletion, and Photo-oxidant formation were avoided due to net electricity production and also fertilizer production as by-products (Chaya and Gheewala, 2007). The difference between anaerobic digestion and composting is shown in Table 2.6.

Table 2.6 Difference between anaerobic digestion and composting

Attributes	Anaerobic digestion	Composting
Types of waste	Sorted organic waste (can be either wet or dry based on the type of AD)	Sorted organic waste (certain ratio of wet and dry organic waste)
Products	Biogas and bio fertilizer (digestate)	Bio fertilizer
Land requirement	Less	More and less based on the type of composting
Skilled manpower	Required	Required
Contribution to waste management	Treat high-quality wastewater, organic waste, sewage sludges, and faecal matter	To treat faecal matter and organic waste
Environmental impact	Emission of methane gas due to lack of skilled workers	Awful odor and low-quality fertilizer due to improper management.
Operational cost	High for automated system	High for in-vessel

2.3.3.4 Thermal treatment technique

Numerous studies confirmed that thermal treatment processes are an important part of a sustainable integrated municipal solid waste management framework (Brunner et al., 2004). Furthermore, it was stated that thermal waste treatment is an important piece of method especially for the management of residues in the waste management frameworks (Sabbas et al., 2003). There are different types of thermal treatment such as incinerator, gasification, pyrolysis, and many more and some of them are discussed below.

(1) Incinerators

Favorable position of incineration is the extensive diminished in the quantity of waste (up to 90%) required to be landfilled (Morris and Waldheim, 1998) and the use of an incinerator has an advantage to convert waste to energy. Some authors even stated that the application and development of waste incineration power generation innovation are the top priority of industrially developed countries (Damgaard et al., 2010; Monni, 2012). But high cost in handling and difficulties in maintaining the required conditions and the low heat value of the wastes made incineration not durable in developing countries (Shekdar, 2009). Furthermore, it was stated that the production of net energy output from the incineration is less when it is compared with an anaerobic digestion scheme (Chaya and Gheewala, 2007).

(2) Gasification

Gasification is the process of production of fuel gas under oxygen efficient conditions by incinerating solid waste (Sharholy et al., 2008). Furthermore, Rong et al. (2015) defined that the thermal process of conversion of solid biomass into the combustible synthetic gas such as H_2 and CO in the absent of oxygen and at a high temperature of 800 °C is called gasification (Rong et al., 2015). For instance, gasification is the primary innovation for conversion of biomass to energy and an appealing option for the thermal treatment of solid waste (Belgiorno et al., 2003). Developed countries use the electricity from the gas produced by the bio gasification of biomass as a mean of reducing greenhouse gas by replacing fossil fuel and developing countries use to provide electricity to rural areas from the traditional biomass (McKendry, 2002). The production of combustible gas, cleaning harmful compound from the combustible gas and the energy recovery system are the three fundamental elements for gasification system (Belgiorno et al., 2003).

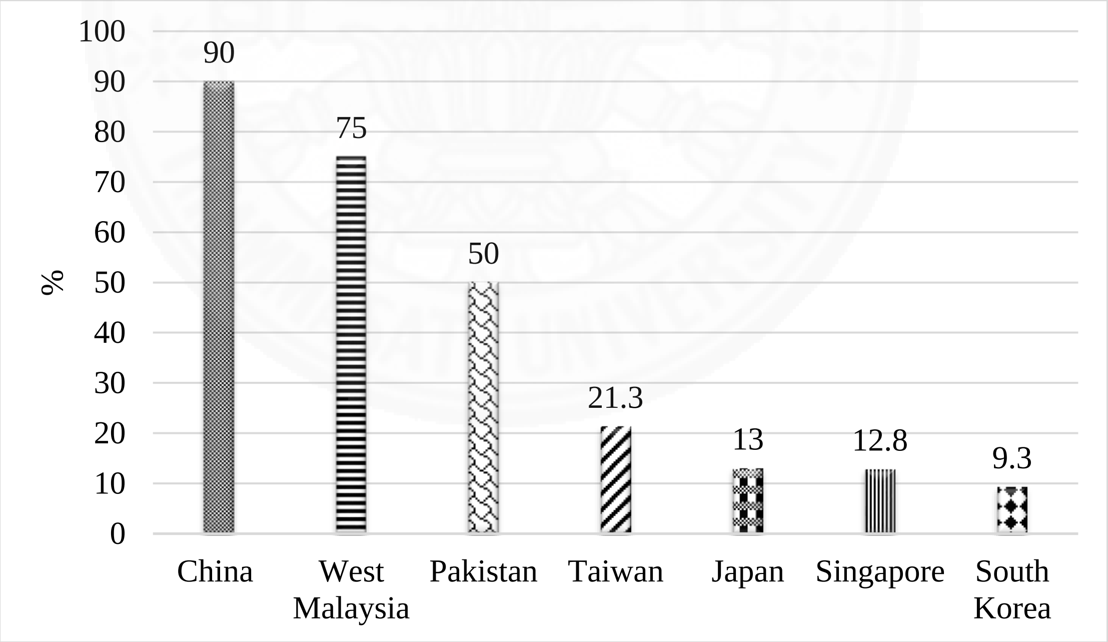
However, because of MSW is highly heterogeneous in nature, with an extensive variety of shapes, sizes, compositions of MSW, prompting variations in syngas yield and syngas yield quality still cause technical and monetary problems (Pinto et al., 2014).

(3) Pyrolysis

Breaking chemical bonds of organic compounds after heating at 500-1000 °C in the absent of oxygen, converting macromolecular compounds into small molecular compounds, for example, solid fuel, fuel gas, and coke is called pyrolysis process and in general, thermal depolymerization is also called decomposition (Yufeng et al., 2003). Hydrocarbon content of the waste is converted into a gas, which is suitable for utilization in either gas engines, with associated electricity generation, or in boiler applications without the need for flue gas treatment (Al-Salem et al., 2009). However, it is not yet adequately developed enough for application for paper sludge but only for the wastes with a high carbon substance, for example, wood, petroleum, and plastic (Monte et al., 2009). The outcomes demonstrated that gasification offered better syngas yield, hydrogen yield and energy yield when contrasted with pyrolysis (Yang et al., 2016). The application of both pyrolysis and incineration in the recent years is mainly for the conversion of waste to energy purpose (Li et al., 1999).

2.3.4 Disposal

The least favorable treatment strategy has been pointed as the landfill or disposal in waste management hierarchy. However, over 70% of municipal solid waste generated is discarded to landfill globally (Slack et al., 2007). The percentage of landfilling in different countries is shown in Figure 2.4. Landfilling rate in developed countries like South Korean (9.3%), Singapore (12.8%), and Japan (13%) and is comparatively low with other countries.



Sources: China (Zhang et al., 2010), West Malaysia (Periathamby et al., 2009), Pakistan (Zuberi and Ali, 2015), Taiwan (Lu et al., 2006), Japan (Shekdar, 2009), Singapore (Bai and Sutanto, 2002), South Korea (Ryu, 2010)

Figure 2.4 The landfilling rate in different countries

In the most part of urban cities, MSW is discarded by storing it in low-lying zones outside the city without following the standards of sanitary landfill (Sharholy et al., 2008). Depending on the quantity and composition of the solid waste dumped at the site, emission of methane from municipal solid waste landfills occurs (Hoeks, 1983). Furthermore, a lot of landfill gas inevitably advances toward the environment (Mor et al., 2006). Up to about 1000 kg CO_2-eq of GHG per ton of waste is emitted from the landfill systems according to Manfredi et al. (2009) (Manfredi et al., 2009). Furthermore, landfill leachates contain countless of compounds, some of which may make a risk to well-being and nature if discharged into the natural habitat (Demirbas, 2011). The concentration and flow rate of leachate vary from site to site, depending on the age of the landfill; young landfill typically contains high amount of volatile leachate (Timur and Özturk, 1999). Therefore, recovering landfill CH_4 and enhancing wastewater treatment can specifically lessen GHG emissions (Bogner et al., 2008).

In low-income country like Bhutan, landfill is commonly used as an ultimate site for disposal and it receives various kind of waste such as medical waste, industrial waste, sludge, food waste, dead animals, commercial waste which cause emission of methane gas followed by air pollution, soil pollution and water pollution.

2.4 MSWM in Bhutan: at glance

The historical backdrop of sustainable waste management in Bhutan is moderately new subject. However, the essential knowledge on waste management isn't new either. In recent years, countless examinations have been attempted to decide powerful factors influencing waste administration frameworks in urban areas in Bhutan. Increasing GDP and changed in consumption patterns of a local citizen is one of the reason of increasing waste management challenges in the country. Bhutan has no source of fossil vitality resources such as oil, flammable gas or any petroleum aside from restricted coal reserves in the southeastern side of the country. Almost 75% of goods are imported from India and some of the imported product includes rice, vehicles, lubricants, machinery, petroleum, food and beverages (World-Bank, 2014).

However, Bhutan has tremendous potential in generating hydropower of 30,000 MW and the yearly rainfall with 500 mm to 5000 mm shifts from North to South respectively (Tshering and Tamang, 2004). Thus, generating hydropower and exporting around 5.61 billion units on yearly average to India is one of the financial sources in Bhutan other than tourism and agribusiness (Dhital, 2009). Furthermore, yearly increment of seasonal populace in the tourism industry also results in increasing municipal solid waste generation (Teh and Cabanban, 2007; Lloréns et al., 2008; Shamshiry et al., 2011). Waste generated per capita in Bhutan from a study of ten urban centers was 0.53 kg in 2007 as shown in Table 2.7. Generally, the source of municipal solid waste comprises of resident waste, commercial waste, office waste, institution waste, organic waste from a vegetable market.

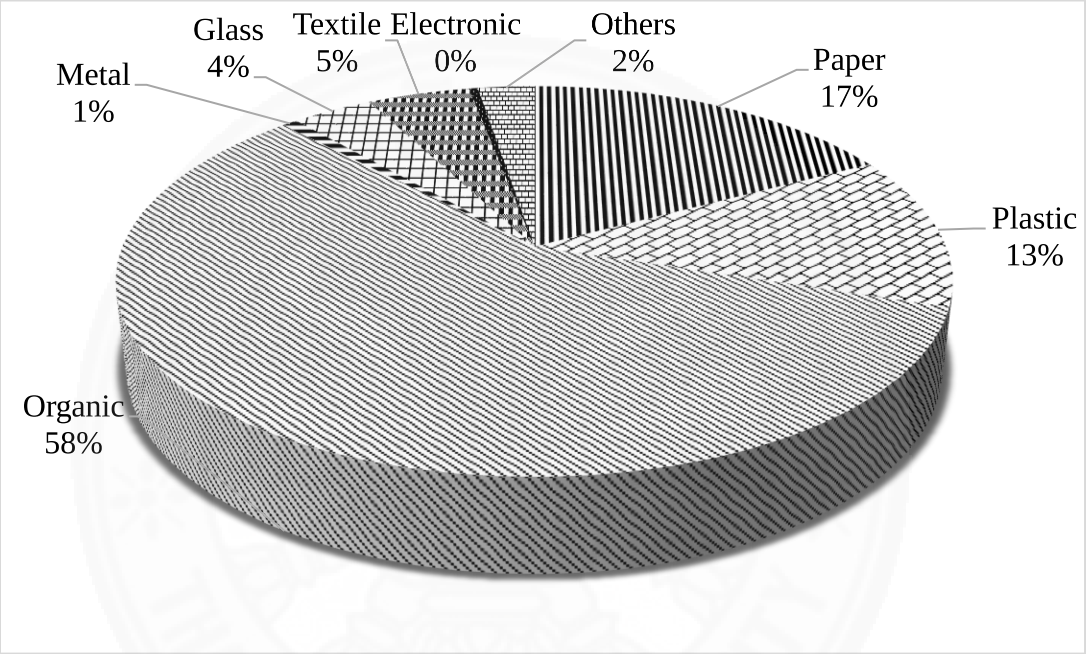
Table 2.7 Waste generation from urban centers in Bhutan

Types of wastes	Generation rates	Quantity	Total qty. generated (tons year $^{-1}$)	% distribution from each source
Household waste	0.25kg/person/day	224,527	21,000	47
Commercial waste	2.36kg/unit/day	20,688 licenses	10,000	23
Office sources	0.21 kg/ employee/day	70,132 employees	5,000	2
Weekly vegetable markets	0.30 kg /person / week	224,527	3,500	8.0
Schools and institutions	0.10kg/person/day	117,734 total enrolled	4,200	10
Total estimated in 2007			43,700	100%
Average per capita total MSW	195kg/capita/year 0.53 kg/ capita/ day			

Source: Phuntsho et al. (2009)

The first waste composition in Bhutan was studied in November to January in the year 2007 and 2008 respectively from ten urban focuses. Waste composition in

Bhutan were organic, paper, plastics, metals, glass, textile, electronic and others as shown in Figure 2.5. The highest waste composition in Bhutan was an organic waste from various sources such as household, commercial sectors, institution sectors and vegetable markets. Recyclable waste from the resident consists of plastics, papers, glasses, and metals and these kinds of waste was mostly sold across Indian border for recycling due to lack of recycling technology in Bhutan.



Source: Phuntsho et al. (2009)

Figure 2.5 Waste composition in Bhutan

Currently, the most common method of waste disposal is landfill which is not even well structure to be called a sanitary landfill. Additionally, there is no waste collection framework implemented in the rural areas yet because of inaccessibility of proper landfills and detached settlements. It is regular practice to burn the refuse inside the pits. Notwithstanding the various waste awareness, regulations, waste campaign and training to private organization and volunteers, the waste administration issue in provincial and other urban communities of Bhutan are different (RAI, 2015).

2.5 Waste management regulations in Bhutan

In spite of the fact that there were attempts and genuine worry to the waste issues previously, the primary real strides towards precise waste administration in Bhutan was the sanctioning of National Waste Prevention and Management Act 2009 (RAI, 2015). Bhutan is an exhaustive bearing for the waste minimization and management after the establishment of Waste Prevention and Management Regulation in 2012 which became effective on 18th of April in the same year. This Regulation is embraced in the Waste Prevention and Management Act, 2009 under Section 53. The National Environment Commission Secretariat (NECS) is the general administrative power in charge of managing and executing the procurements in the Act and Regulation (RAI, 2015). The Regulation distinguishes the work and obligations of various stakeholders to guarantee effective waste management system as shown in Table 2.8.

Table 2.8 Waste Prevention and Management Strategy, Act, and Regulation in Bhutan

Document	Type	Purpose	Lead Responsible Authority
National system, activity design incorporates solid waste management, 2007.	Strategy	Gives direction on how waste, which may negatively affect human health and the environment, can be expelled routinely and moderately	Ministry of Works and Human Settlement, National Environment Commission
Waste Prevention and Management Act, 2009	Act	Decreases waste generation at source; advances separation, reuse, and recycling; discards waste in an environmentally effective way; and guarantees viable working and coordination among executing organizations	Ministry of Works and Human Settlement, city corporation, dzongkhag and gewog (village group) councils supported by their organizations.

Document	Type	Purpose	Lead Responsible Authority
Waste Prevention and Management Regulation, 2012	Regulation	Sets up strategies to execute the Waste Prevention and Management Act, 2009.	Ministry of Works and Human Settlement, city corporation, dzongkhag and gewog councils supported by their organizations

Source: (Gawel and Ahsan, 2014)

The National Environment Commission hereby endorse the Waste Prevention and Management (Amendment) 2016, on 6/8/2016 in its 43rd meeting as follows: Title, Commencement and Extent 1. This Regulation might:

a) Be called the Waste Prevention and Management (Amendment) Regulation, 2016

b) Come into impact on 8th November 2016

c) Extend to entire of Bhutan

2.6 Environmental impact potential from solid waste management

The components influencing the solid waste management in terms of environment in developing nations are the absence of assessment of the environmental impact and control frameworks (Matete and Trois, 2008). Presently, Bhutan is a net carbon sink as the evaluated sequestration limit of forest is 6.3 million tons of CO_2 while the emission was just 1.6 million tons of CO_2 equivalent in 2000 as per the second national GHG inventory (Thimphu, 2002). However, environmental impact potential from different sources of waste management might be serious issues in the future. Table 2.9 shows examples of some of the potential impact from transportation, material recovery facilities and landfill. Accumulation of huge amount of heavy metals takes place in the landfills, which contribute extraordinarily to this hazard potential.

Table 2.9 Sources, emissions and potential impact of waste management methods

Sources	**Emissions**	**Potential environmental effects**
Transportation	Carbon monoxide, carbon dioxide, nitrogen oxides, particulate matter, metals, rubber dust and VOCs emission from the vehicle. Spillages of VOCs, dust, odour, litter from accidental situation	Exposure to exhaust fumes potential along transportation road and at transfer station
	Surfactants, diesel and petrol from fuel derived VOCs from cleaning	Ground water or surface water contamination potential
Materials Recycling Facility	Dust and odour Organic compounds, produce residues, surfactants	No significant effects likely
	Contaminants traces like metals and organic compounds might be present in original compost feedstock.	Potential in increasing contamination in soil from the original compost feed stocks
Landfill	Miro-organisms, dust, litter, odour and landfill gas like compounds CH_4, CO_2); exhaust gases from combustion of landfill gas (including carbon dioxide, carbon monoxide, oxides of nitrogen, sulphur dioxide, and other trace components)	Potential for soil acidification due to deposition of acid gases; increases in soil metals; vegetation damage due to oxides of nitrogen (NO_x) and sulphur dioxide (SO_2)
	Leachate containing salts, heavy metals, biodegradable and persistent organics to groundwater, surface water and sewer	Potential for contamination of ground and surface water with metals, organic compounds, bioaccumulation of toxic materials
	Metals (Zinc (Zn), lead (Pb), copper (Cu), arsenic (As)), and various organic compounds	Potential for contamination of flora and fauna in contact with contaminated land, and possible bioaccumulation of toxic materials in flora and fauna

It is an essential to know the effects from the waste management alternatives during waste management planning.

2.7 Life Cycle Assessment (LCA)

In numerous studies, Life Cycle Assessment tool has been utilized for effective municipal waste management since it helps with the environmental assessments of alternative waste management frameworks and/or for the recognizable proof of those main areas requiring potential development (Koci and Trecakova, 2011). Yoshida et al. (2007) stated that an application of LCA computer model to evaluate the environmental effect of municipal solid waste management frameworks can be very effective (Yoshida et al., 2007). Various waste management scenarios were compared using different types of LCA software. The comparative study results would be helpful for decision-making processes to evaluate the environmental performance of the solid waste management system (Erlandsson and Borg, 2003). Some authors focused on aspects related to the management of waste disposal processes, comparing the environmental impacts of alternative treatment systems are shown in Table 2.10.

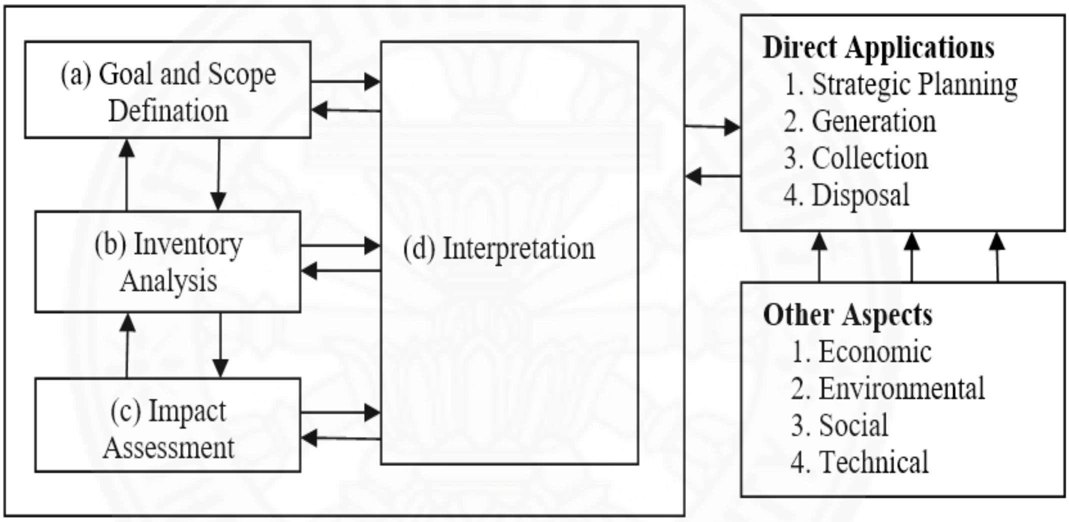
Table 2.10 The utilization of LCA technique in solid waste management

Country	**Functional unit (FU) and Software**	**Scenarios**	**Results**
Singapore (Tan and Khoo, 2006)	FU per year generated MSW SimaPro software	S1. Recycling S2. Composting S3. Incineration S4. Landfilling	Recycling situation had the most minimal GHG outflow, among the waste management options
Thailand (Chaya and Gheewala, 2007)	FU 1 t MSW SimaPro5 software	S1. Incineration S2. Anaerobic digestion	Anaerobic digestion option was desirable over incineration. This was because 60% of the waste was biodegradable
UK (Emery et al., 2007)	FU 101,000 t MSW WISARD software	S1 landfill S2. Waste recovery S3. Recycling, composting and incineration	Incineration scenario was the best when it is compared with the landfill and recycling/composting alternatives from the result

Country	**Functional unit (FU) and Software**	**Scenarios**	**Results**
		S4. Incineration	
Taiwan (Chen and Lin, 2008)	FU 1 t MSW WASTED software	S1. Collection and transportation S2. Recycling S3. Incineration S4. Composting S5. Landfilling	The outcome demonstrated that recycling was the best strategy for diminishing the greenhouse gas
Turkey (Banar et al., 2009)	FU 1 t MSW SimaPro7 software	S1. MRF S2. Recycling S3. Composting S4. Incineration S5. Landfilling	The outcome demonstrated that as indicated by the correlation and affect ability examination, composting situation was the best option than different alternatives.
Sweden (Zaman, 2010)	FU 1 t MSW SimaPro7 software	S1. Pyrolysis gasification S2. Incineration S3. Sanitary landfill	The outcome demonstrated that the sanitary landfill and the incineration had the most astounding Global warming potential because of high carbon dioxide emanation. Acidification impact was highest from the incineration among the alternative options because of emission of SO_x and NO_x
Iran (Abduli et al., 2011)	FU 1 t of MSW Land Gem software Eco Indicator 99 method	S1. Landfilling S2. Composting and landfill	The outcome demonstrated that landfilling had a lower environmental impact in compare to scenario 2

Databases used for environmental evaluation vary according to users, application, data, geographical location and scope. Some of the examples of database are CML, DEAM TM, Ecoinvent Data, GaBi 4 Professional, IO-database for Denmark 1999, SimaPro database, the Boustead Model 5.0 and US Life cycle inventory database (Erlandsson and Borg, 2003). The Ecoinvent database is at present the most generally utilized LCI database because it includes all significant environmental streams, for example, asset extractions, utilize usage and outflows, and in addition all material and vitality sources of info and results of processes. Example: Ecoinvent database was used for inventory analysis of HDPE to assess the environmental impact of plastic recycling in Qatar (Al-Maaded et al., 2012).

LCA consists of the following four major interrelated phases as shown in Figure 2.6: (a) definition of goal and scope, (b) life cycle inventory (LCI) that identifies inputs and outputs for each process or material, (c) life cycle impact assessment (LCIA), and (d) interpretation.



Source: Yadav and Samadder (2017)

Figure 2.6 Components of life cycle assessment

a) Definition of goal and scope

In life cycle analysis, defining goal and scope is the initial phase where the product is characterized for to be evaluated, and additionally the setting of the appraisal to be made. This progression is vital in the LCA procedure. It affects the effect evaluation step as numbers of parameters are distinguished, for example, required resources and time, the purpose behind the study, the expected application, the framework limits, method used for impact assessment, and the general presumptions.

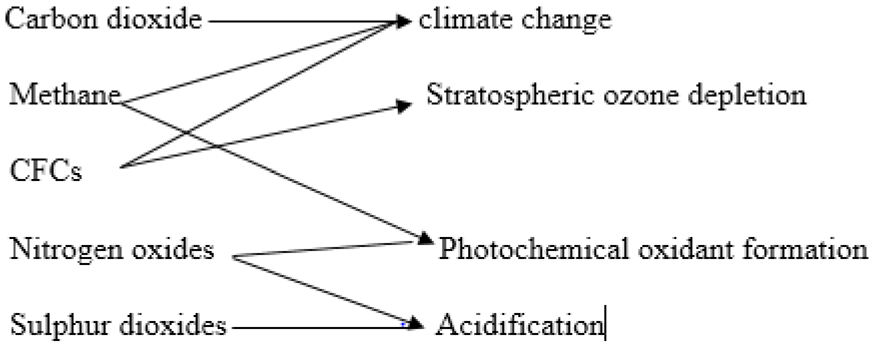
b) Life cycle inventory analysis

The consequence of analysis of inventory step is a list of amounts containing the utilization of materials and consumption of energy all through the diverse phases of the life cycle of product/process. Consequently, in the inventory examination step, the related materials and energy consumed of an item are disclosed with a specific end goal to show the item and its aggregate sources of input from the natural environment and output to the natural environment (Rebitzer et al., 2004). The LCI study depends upon on the sorts and amounts of natural resources like energy, water and so forth, the utilized materials to produce the item and the techniques used for transportation process, the path in which the item is utilized during its life expectancy, and how the item is at last discarded. The impacts and consideration of these variables cannot be quite the same as one area to another (Menoufi, 2011).

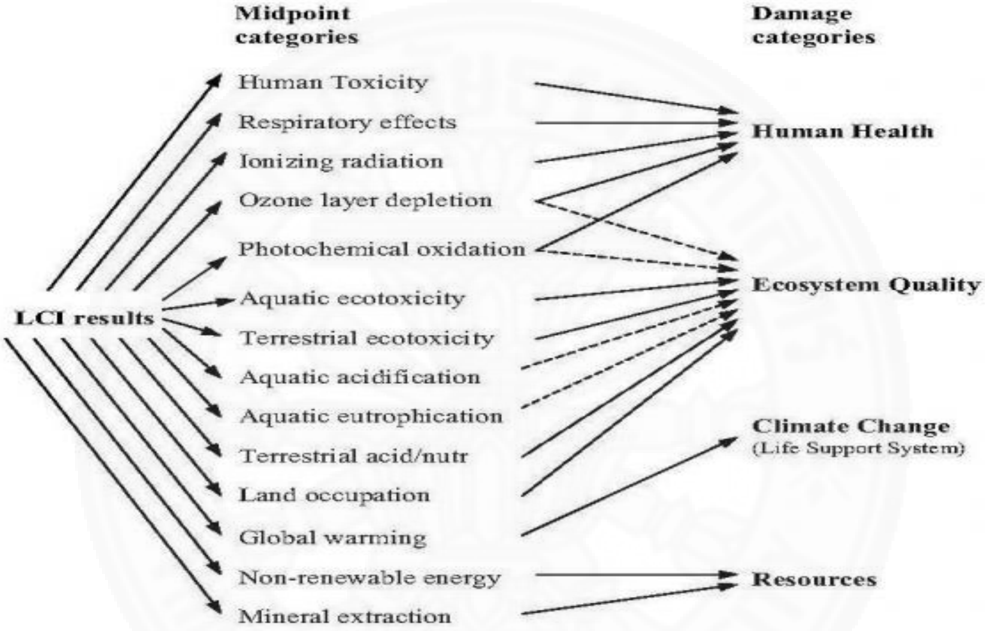
c) Life cycle impact assessment

Objective of impact assessment is to understand and evaluate the extensiveness and significant of the potential environmental impacts of a product system. Life cycle inventories by themselves do not characterize the environmental performance of a product system. Impact assessment (IA) aims at connecting, to the extent possible, emissions, and extractions listed in LCIs on the basis of impact pathways to their potential environmental damages. According to ISO 14042, LCI results are first classified into impact categories that are relevant and appropriate for the scope and goal of the LCA study.

Example:



There are currently two main Impact Assessment (IA) methods such as problem oriented IA methods and damage oriented IA. Problem oriented IA methods stop quantitative modeling before the end of the impact pathway and link LCI results to so-defined midpoint categories (or environmental problems), like Acidification and Ozone depletion. Damage oriented IA methods, which model the cause-effect chain into the endpoints or environmental damages, link LCI results to endpoint categories. Example of midpoint and damage categories is shown in Figure 2.7.



Sources: (Jolliet et al., 2003; Menoufi, 2011)

Figure 2.7 Example of Midpoint and Damage categories

d) Impact characterization

After the selection and defining the impact categories, the corresponding contribution of each input and output inside the product/item framework to the environmental load is appointed to these impact categories and converted into indicators that represent to the comparing potential impacts on the environment. The results of the inventory acquired in the classification phase is multiply by the characterization factors of each substance within each impact category as expressed in equation (1) (Menoufi, 2011).

$$\text{Category Indicator} = \sum \text{characterization Factor (s)} \times \text{Emission Inventory (s)} \tag{1}$$

Where subscript s denotes the chemical

The equation (1) of characterization factors straightly express the contribution of a unit mass (kg) of an emission to the environment. For instance, the corresponding contribution of various gasses to climate change are usually collected and analyzed in terms of carbon dioxide equivalents utilizing the potential of Global warming.

e) Normalization

It represents in such a way that enables the impact indicators to contrast with each other. This is done by dividing the sum of each category indicator result with reference value as per the equation (2) (Menoufi, 2011).

$$N_k = S_k / R_k \tag{2}$$

Where k signifies the classification of impact, N represent as a normalized indicator, S indicates the category marker from the characterization and R is the normalization factor or reference value.

The real or potential magnitude of the corresponding impact category potential magnitude of the corresponding impact category for a geographic range and over a specific time span are usually represent by the selection of the normalization factors. An example of a reference value is the annual national United States contribution to climate change in terms of GWPs.

f) Interpretation

In this progression, the result of impact evaluation is interpreted, and develop conclusions, keeping in mind that the end goal to guide the decision-making process. The critical environmental issues are characterized, and the importance of the relative commitment of a specific procedure to the environmental load is perceived. It also ensures that each of the stages are consistent with each other (e.g., the analysis matches the purpose defined in the goal and scope definition in LCA study).

Chapter 3
Materials and Methodology

This chapter explains the methodology of research. This study focuses on case study technique to collect the primary data through utilizing three examination strategies which are in-depth interview, observation of current condition of MSWM system through a site visit and random waste sample collection from different categorized hotels and households in Paro district. To discover the suitable techniques to take care of the environmental impact of current MSWM in the study area, contrast situations or scenarios were developed. SimaPro8.3 and CML2 Baseline 2000 method was used to compare the alternative scenarios.

3.1 Study area description

Paro Dzongkhag (district), located in the northwestern part of Bhutan (shown in Figure 3.1) was selected as a study site to fulfill the targets of this research work. Paro is a standout amongst the most fertile district in the kingdom of Bhutan producing a huge amount of local red rice from its terraced fields. Furthermore, expanding vegetable production like cabbage, potato, carrot, and beans and exporting to India is one of the key execution economic in Paro (Kuensel, 2016). The number of inhabitants in the study area is quickly expanding because of high rate of relocation of individuals from different parts of the district looking for new opportunity and better life. The population in Paro region has been raising from 39,800 to 43,167 in 2010 and 2015 respectively (NSB, 2016).

In 1983, the newly shaped national airline “Druk Air” in Paro air terminal was started to operates flights from Calcutta, utilizing little turbo-prop Dornier aircraft (Brunet et al., 2001). The distance between Paro airport and Thimphu, the capital city of Bhutan is only 50 km. Paro district is also one of the most standouts amongst the most alluring tourist destinations to visit Bhutan as it has many sights seeing places, like Tiger's nest on the side of a cliff which is 900 m above the Paro valley, many luxury resorts, national museum and historic religious temples and religious festival attracts many tourists (Royal-Government-Bhutan, 2014).

Source: (NSB, 2016)

Figure 3.1 Map of Paro district

Paro district is divided into 10 administrative blocks/gewogs such as Dokar gewog, Dopshari gewog, Doteng gewog, Hungrel gewog, Lamgong gewog, Lungnyi gewog, Naja gewog, Shapa gewog, Tsento gewog and Wangchang gewog. These Gewogs has 50 chiwogs (chiwogs are former third-level administrative divisions under the Gewog) with 281 villages and 7,118 households. This study mostly focused on 14 villages (Shaba, Satsam, Lango, Damsebhu, Olathang, Changnanka, Khangkhu, Wangchang, Taju, Shomu Langong, Janka, Khangkhu, Gantey and Geptey) out of 281 villages. Table 3.1 shows the brief description of Gewogs in Paro district.

Table 3.1 Brief description of Gewogs in Paro district

Gewogs	Brief description
Tsento gewog	Location: North of the district
	Area: 575.1 sq.km, Chiwogs: 5, Villages:18 and Households:905
Dokar gewog	Location: West of the district
	Area: 106.1 sq.km, Chiwogs: 5, Villages: 21 and Household: 327
Dopshari gewog	Location: South of the district
	Area: 36.7 sq.km, Chiwogs:21, Villages:24 and Households: 619
Doteng gewog	Location: North of the district
	Area:193.1 sq.km, Chiwogs: 5, Villages:10 and Households: 190
Hungrel gewog	Location: East of the district
	Area: 3.6 sq.km, Chiwogs: 5, Villages: 13 and Households: 344
Lamgong gewog	Location: West of the district
	Area: 48.8 sq.km, Chiwogs: 5, Villages: 17 and Households: 706
Lungnyi gewog	Location: Central region of the district
	Area:59.7 sq.km, Chiwogs: 5, Villages: 8 and Households: 567
Naja gewog	Location: South of the district
	Area:51.8 sq.km, Chiwogs: 5, Villages: 15 and Households: 611
Shapa gewog	Location: West of the district
	Area:76.4 sq.km, Chiwogs:5, Villages:21 and Households: 1,508
Wangchang gewog	Location: Center of the district
	Area:34.2 sq.km, Chiwogs:5, Villages:34 and Households: 1,341

3.2 Research framework

Data collections were conducted in three different parts: (1) stakeholder interview about waste management system, (2) site observation, (3) random waste sample collection from different households and hotels to discover the individual effect on municipal solid waste management. This data gathering for Paro contextual investigation was held in 2016 from October to November (tourist peak season). Using these results, different scenarios were proposed and compared an environmental impact potential within those scenarios using the LCA model. The figure shown below is the theoretical framework for this study.

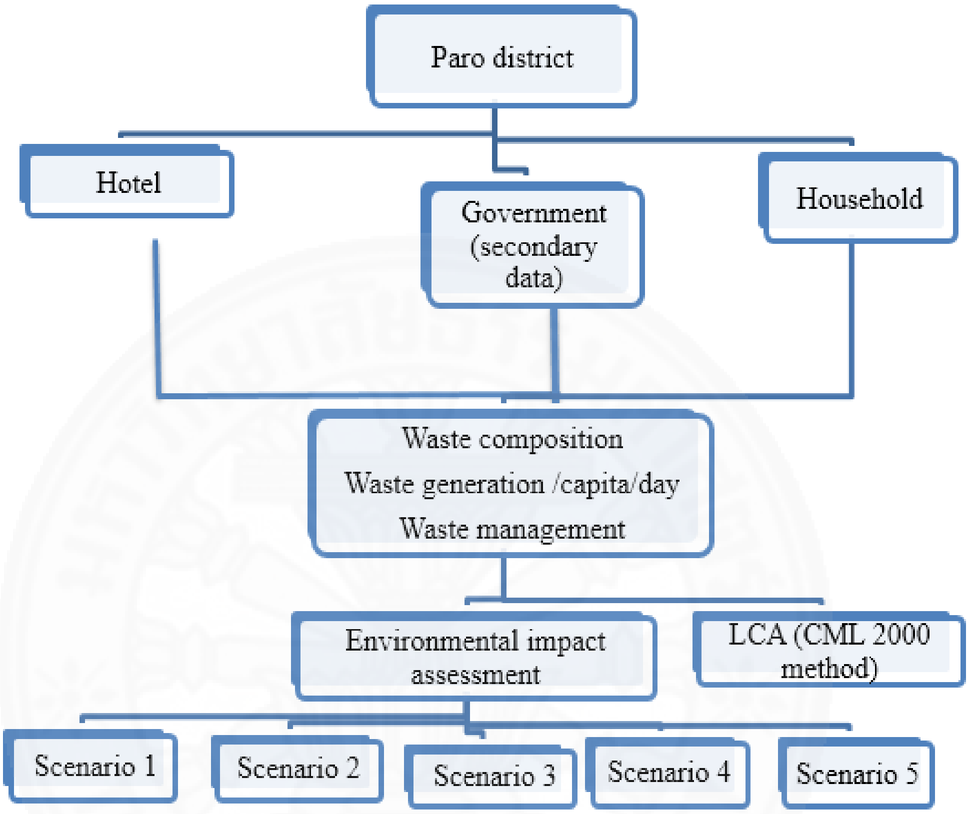


Figure 3.2 Research framework

3.3 Methods for data collection

3.3.1 Interview

- **Government and private sectors**

For the information relating to the present waste management practices, current issues and constraints, officials of the Paro municipal were interviewed based on semi structured schedules. Similarly, the private organization in Paro district who is also responsible for solid waste collection and management were interviewed to obtain information on the number of vehicles, their collection schedule and challenges faced during waste collection and transportation. Furthermore, information on availability of waste management programs and quality of participation by the local people and the financial support from the government and private sectors was also obtained.

- **Household and hotel sectors**

For the information in terms of public attitude and opinion on solid waste management practices, waste composition, waste separation at source, waste collection schedule, waste disposal practices, eagerness to pay more for waste management services and waste management programs and training in hotel industry were collected through interview from households and hotels in various location. Five different sampling areas, namely, (Olathang, Gaptey, Gantey, Shaba and town) was randomly selected for household study and information was collected through interviewing four family units from each sampling area. Similarly, five different hotel categories starting from one star to five-star hotels were selected from different location and interviewed. Further detail on study sites are explained in “site selection for waste composition study”.

3.3.2 Waste composition study

To discover the present practices in terms of solid waste management system, site observation was carried out simultaneously. Onsite observation for certain destinations included were the dumping place in some of the hotels and households and landfill site. There was no transfer station and any recycling centers/compost operating plants in Paro. Pictures of sites observed are shown in Appendix one.

- **Sampling method**

Sampling was carried out at the landfill site according to international standard ASTM D5057-10 and ASTM D5231-92 (2008) as shown in Table 3.2. The determination of the mean composition of MSW was based on the collection and manual sorting of number of samples of waste over a selected time period covering one week for each site.

Table 3.2 Analytical parameters

Item	Parameter	Analytical parameters
1	Density	ASTM D5057-10
2	Physical compositions	ASTM D5231-92 (2008)

Density of solid waste was measured by filling the waste into 20 L (volume) of bucket and weighed. The density of waste was calculated to identify the waste composition and generation per day per person, and the daily waste load weights collected by the trucks were used to estimate the total waste entering to the landfill site in one day which was repeated for 7 days consecutively. This study does not cover the rate of waste collected by informal waste pickers/ wanders available to sale waste from community bins.

- **Site selection for waste composition study**

The screening of study was determined by following two criteria which are “star category and location” for the selection of hotels as shown in Table 3.3. The waste was collected for seven consecutive days from each hotel.

Table 3.3 Selection of hotels

Total number of hotels	Sl.no	Name of hotels	Star	Location (Distance from the landfill)
5 stars = 6	1	Le Meriden Riverfront	5*	Shaba (2.9 km)
	2	Hotel Zhiwaling	5*	Satsam Chorten (10 km)
4 stars = 3	3	Kitchu resort	4*	Lango (6 km)
	4	Raven’s Nest	4*	Satsam Chorten (10 km)
	5	Tashi Namgay Resort	4*	Damsebhu (7 km)
3 stars = 3	6	Tiger’s Nest Resort	3*	Satsam (9.8 km)
	7	Tenzingling Resort	3*	Lango (5 km)
2 stars= 9	8	Hotel Olathang	2*	Olathang (9 km)
	9	Hotel Tashi Phuntshok	2*	Changnanka (9 km)
	10	Drukchen	2*	Khangkhu (8.5 km)
	11	Mandala	2*	Wangchang (10 km)
	12	Hotel Gangtey Palace	2*	Taju (9.8 km)
	13	Bhutan Metta Resort	2*	Shomu Langong (9 km)
1 star = 9	14	Namsaycholing Hotel	1*	Shomu Langong (7.5 km)
	15	Pelri cottage	1*	Olathang (9.5 km)
	16	Pegyel Hotel	1*	Shaba (2.9 km)
	17	Janka Resort	1*	Janka (8.5 km)
	18	Khangkhu Hotel	1*	Kangkhu (9 km)
Total= 30				

However, the site selection of the households was determined by only one criteria that was “different locations” as shown in Table 3.4. Similarly, waste was collected for seven consecutive days from each household unit from various locations. This study represents 7,118 the number of households in the Paro district.

Table 3.4 Selection of households

Sample number	Household	Location (Distance from the landfill)
19	Building 1	Olathang (9 km)
20	Building 2	Gantey (2 km)
21	Building 3	Paro town (11 km)
22	Building 4	Geptey (9.8 km)
23	Building 5	Shaba (2.9 km)

3.3.3 Life Cycle Assessment (LCA)

SimaPro8.3 software is used to develop LCA studies of wide range of waste management scenarios. Although it is not designed specifically to carry out LCA of waste, the complete databases, and the flexibility of the impact assessment methodologies included, makes it suitable for this purpose. The alternative scenarios will be compared through CML2 baseline 2000 method.

3.3.3.1 Objectives and Scope of LCA

The objective of the present study is to identify the environmental burden of current solid waste management system and exchange-off under various waste management system scenarios through comparison, keeping in mind the end goal to propose the best methodology for local authorities and government. Goal and scope definition is the primary stage in a life cycle assessment containing the fundamental issues:

(1) Funtional Unit

One ton of municipal solid waste of Paro district is used as the functional unit for the comparison of the alternative scenarios. Waste composition of hotel and household sectors are included in one ton of municipal solid waste.

(2) System boundary

This study involves waste transportation and waste treatment options like recycling, composting and landfilling of waste as shown in Figure 3.3. Hard plastic, soft plastic, glass, aluminum and paper are treated by recycling. The composting process include only food waste. The waste fractions enter the system boundary without any environmental burden from production and material used. Within the system boundary, all contributions to the framework like 1 ton of MSW and vitality necessity for the procedures and all yields like outflow to the air water or soil have been incorporated.

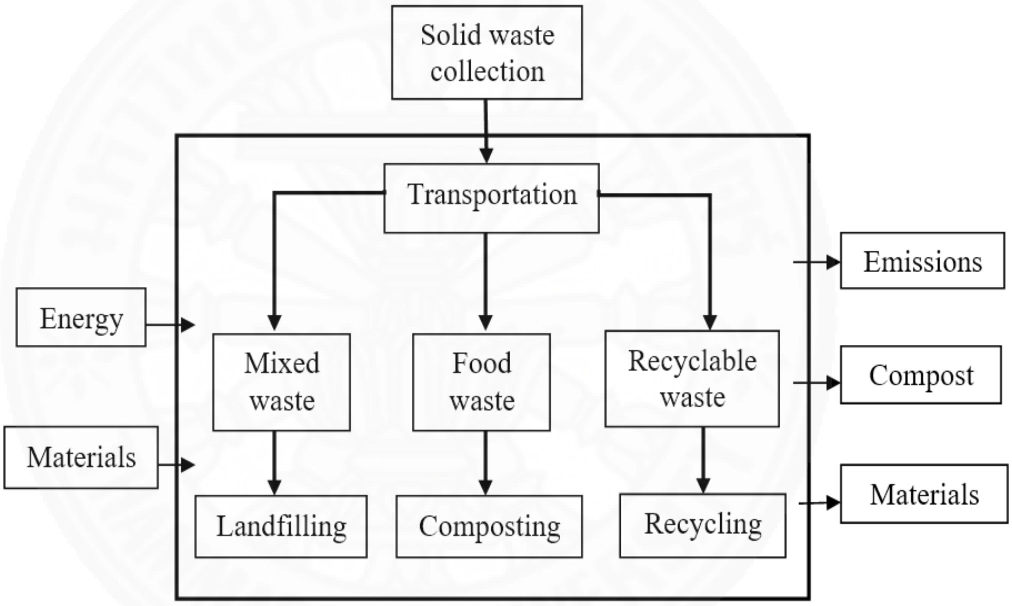


Figure 3.3 System boundary

3.3.3.2 Description of scenarios

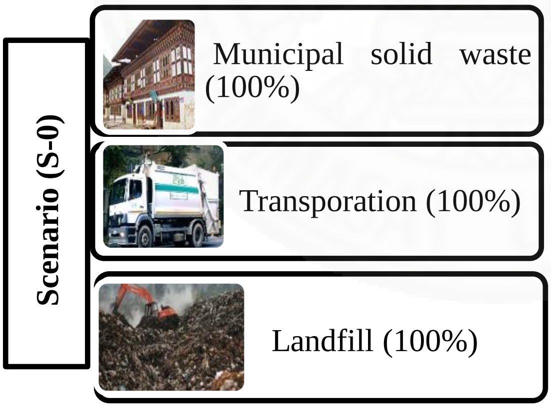
In this study, composting and recycling scenarios is taken more focus for environmental impact assessment since it has high tendency of reducing waste in the landfill. Organic waste constituted a high measure of waste reduction in the landfill, if it is used for composting process. Additionally, if recyclable waste is separated for recycling process and reusing practices, the landfill life expectancy will increase and reduce the environmental and health issues. The alternative waste treatment scenarios developed include Scenario-0 (100% landfill), Scenario-1 (50% of composting), Scenario-2 (50% of recycling), Scenario-3 (25% of recycling and 25% of composting), and Scenario-4 (50% of recycling and 50% of composting). Further detailed explanation of this proposal scenario is explained below:

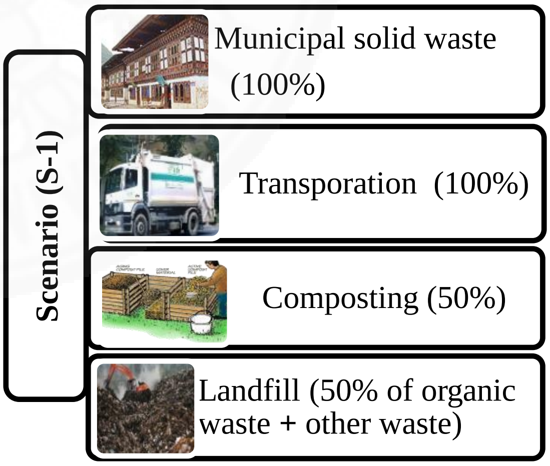
(1) Scenario-0 (100% landfill)

Solid wastes which are generated from the household sectors and hotel units are dumped in the landfill with no source separation and treatment. The serious problem of moving leachate and releasing gas from the landfill into the surrounding area is the environmental concerns and health worries. A generalization of the existing waste management system acts as a scenario-0 with sanitary landfill instead of open landfill against which all other scenarios are compared.

(2) Scenario-1 (50% composting)

This scenario importantly focuses on the organic waste in which composting activity is added to the scenario-0 waste management situation. In this scenario, 50% of total organic waste generated is used for composting and the remaining 50% of organic waste along with other type of waste are disposed in the landfill.



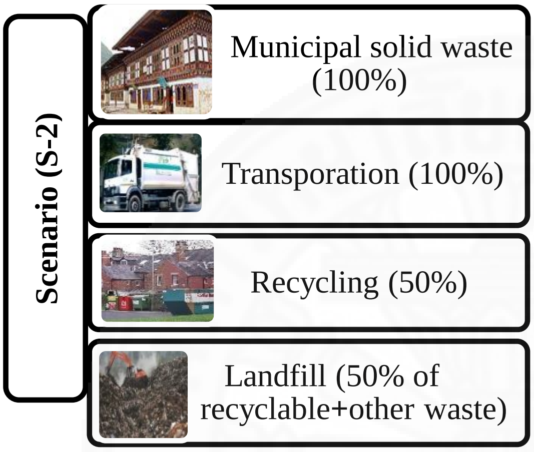


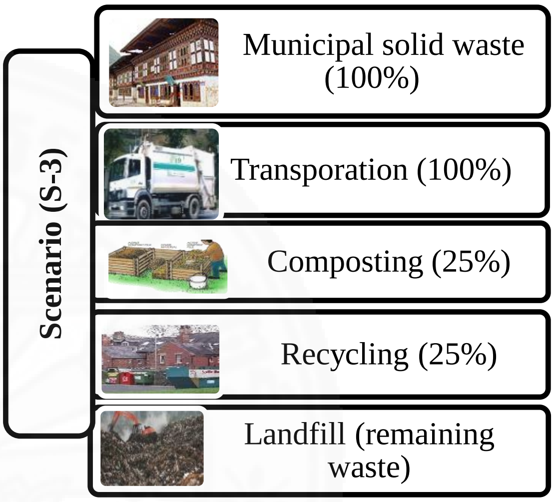
(3) Scenario-2 (50% recycling)

This scenario importantly focuses on recyclable waste where recycling activity is added to the scenario-0 waste management situation. In this scenario, 50% of recyclable waste materials is used for the recycling activity and the remaining 50% of organic waste along with other type of waste are disposed in the landfill.

(4) Scenario-3 (25% recycling and 25% composting)

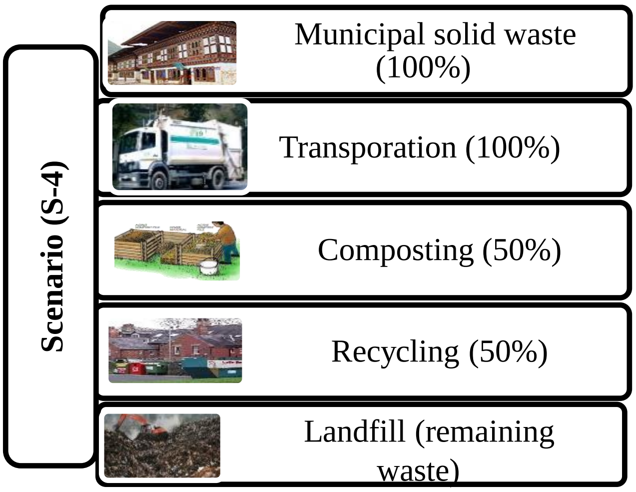
This scenario is the combination of scenario-1 and scenario-2, but the percentage added in this scenario is 25% of total recyclable waste is used for recycling and 25% of total organic waste is used for composting. The remaining 75% of organic waste and 75% of recyclable waste are added in the landfill along with other type of waste.





(5) Scenario-4 (50% recycling and 50% composting)

The scenario is same as the previous scenario with the combination of composting and recycling scenarios, however, the percentage added in this scenario-4 is the combination of 50% of total recyclable waste and 50% of total organic waste. The remaining 50% of organic waste and 50% of recyclable waste along with other type of waste are added to the landfilling system.



3.3.3.3 General assumptions

For aspects where no specific or published data were available, assumptions were made based on well-founded arguments. Assumptions made in this research are as follows:

1) Transport distance of waste for all processes (landfill, composting and recycling sites) is assume as 11km since there is neither composting site nor recycling center in Paro district. Therefore, composting and separation of recyclable material occur at the landfill site.
2) The current waste management practices in Paro is assumed to be sanitary landfill instead of open landfill.
3) Regarding the modelling of the waste treatment scenarios along with transportation for the different solid waste fractions, the significant information is acquired from the ecoinvent v3 database since information are not accessible for Paro's solid waste management framework. This is because most of the waste compositions are used to calculate the disposal inventories in the ecoinvent v3 database for various waste treatment plants and landfilling (Doka, 2003).
4) Input data used for waste material like rubber, glass and other waste disposed in the landfill are assumed to be municipal solid waste as software tool is very limited for the types of material available.

3.3.3.4 Inventory Analysis

The life cycle inventory analysis aims for distinguishing and evaluating the ecological intercessions crossing framework limits. The life cycle inventory data is collected from the waste characterization study of Paro, literature and SimaPro8.3 database. Databases in the software were studied and relevant data was filtered and add to the inventory. The inventory data include gases and leachate from landfills and air emissions from recycling, composting gases, and transport pollution. The inventory data of waste fractions which was previously described in the scenarios is shown in Table 3.5.

Table 3.5 Waste fraction and waste treatment scenario as an inventory data

Waste composition (Kg)	Waste treatment scenarios (1000 kg)				
	S-0	S-1	S-2	S-3	S-4
	Landfill **(100%)**	Composting **(50%)**	Recycling **(50%)**	Recycling **(25%)** and composting **(25%)**	Recycling **(50%)** and composting **(50%)**
Food waste	500	250		125	250
Paper	110		55	27.5	55
Glass	110		55	27.5	55
LDPE	90		45	22.5	45
Textiles	65				
Aluminum	50		25	12.5	25
Rubber	35				
HDPE	30		15	7.5	15
Other waste	10				
Total waste to landfill (kg)	**1000**	**750**	**805**	**777.5**	**555**

For the modelling of the vehicles used for waste transportation, the processes of the ecoinvent system v3 database was used. SimaPro provides six libraries that each contain all the processes that are found in the ecoinvent database, but use different system models and contain either unit or system processes. The three ecoinvent system models are (1) Allocation, recycled content, (2) Allocation, default and (3) Consequential. The ecoinvent system model used in this study is Allocation, default-unit. An allocation dataset means that the principles of attributional modeling have been applied. For transportation of solid waste to the recycling center and composting site assume to be the same distance as a landfill site, shown in Table 3.6.

Table 3.6 Ecoinvent process system of transport

Transport vehicle (Ecoinvent process system)	Distance	Unit
Municipal waste collection service by 21 metric ton lorry {RoW}, | processing | Alloc Def, U	11	tkm

Regarding the modelling of the waste treatment plants for the different solid waste fractions unfortunately, some site-specific data are not available, and this is a limitation of the study; for this reason, the processes of the ecoinvent v3 database was used, as shown in Table 3.7.

Table 3.7 Ecoinvent process of waste materials

Process	Material	Ecoinvent system process
Landfill	Hard plastic	Waste polyvinylchloride {RoW}|treatment of waste polyvinylchloride, sanitary landfill | Alloc Def, U
	Soft plastic	Waste polyethylene terephthalate {RoW}| treatment of waste polyethylene terephthalate, sanitary landfill | Alloc Def, U
	Glass	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U
	Textile	Landfill of textiles EU-27
	Food waste	Landfill of food waste EU-27
	Aluminum	Waste aluminum {RoW}| treatment of, sanitary landfill | Alloc Def, U
	Paper	Waste paperboard {RoW}| treatment of, sanitary landfill | Alloc Def, U
	Rubber	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U
	Other waste	Municipal solid waste {RoW}| treatment of, sanitary landfill | Alloc Def, U
Composting	Food waste	Bio-waste {RoW}| treatment of, composting | Alloc Def, U
Recycling	PVC	PVC (waste treatment) {GLO}| recycling of PVC | Alloc Def, U
	PET	PET (waste treatment) {GLO}| recycling of PET | Alloc Def, U
	Glass	Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | Alloc Def, U
	Aluminum	Aluminum (waste treatment) {GLO}| recycling of aluminum | Alloc Def, U
	Paper	Paper (waste treatment) {GLO}| recycling of paper | Alloc Def, U

3.3.3.5 Impact Assessment

Impact assessment focus on understanding and assessing the size and centrality of potential environmental effects of a framework. LCI inputs data and outputs are sorts out into particular impact categories and models the input sources and outputs for every category. The LCIA characterizes the environmental impacts associated with the emissions and mass flows calculated in the LCI (e.g., Global warming potential from CO_2, CH_4, and N_2O) as shown in Table 3.8.

Table 3.8 Example of classification and characterization factor

Impact category	Examples of LCI data (Classification)	Common possible characterization factor	Description of characterization factor
Global Warming	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	Chlorofluorocarbons(CFCs) Hydro chlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Ozone layer Depletion Potential	Converts LCI data to trichlorofluoro-methane (CFC-11) equivalents.
Acidification	Sulfur Oxides (SO_x) Nitrogen Oxides (NO_x) Hydrochloric Acid (HCL) Hydrofluoric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents
Eutrophication	Phosphate (PO_4) Nitrogen oxide (NO) Nitrogen dioxide (NO_2) Nitrates (NO_3) Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) equivalents
Photochemical Smog	Non-methane hydrocarbon (NMHC)	Photochemical Oxidation Potential	Converts LCI data to ethane (C_2H_6) equivalents

There are several methods available for obligatory impact categories (category indicators used in most LCAs); this study was conducted by a midpoint approach following the ISO 14040 series of standard and using CML2 baseline 2000 method based on the principle of best available practice. It is also probably the most up-to-date, includes a balanced set of impact categories, and does not employ debatable damage units, nor lumps results into a single over simplistic "super-indicator". This strategy was initially created in 1992 by Center for Environmental Studies (CML) of the University of Leiden, the Netherlands. The most suitable impact categories were performed as shown in Table 3.9.

Table 3.9 Impact categories and units employed in CML method

CML category	Unit
Abiotic Depletion Potential (ADP)	Kg Sb equiv.
Acidification Potential (AP)	Kg SO_2 equiv.
Eutrophication Potential (EUP)	Kg PO_4 equiv.
Global Warming Potential (GWP)	Kg CO_2 equiv.
Ozone Layer Depletion (ODP)	Kg CFC 11 equiv.
Photochemical Oxidation (PO)	Kg C_2H_4 equiv.
Human Toxicity Potential (HTP)	Kg 1,4-dichlorobenzene equiv.

(1) Abiotic Depletion Potential (ADP)

The Abiotic depletion potential is determined for each extraction of minerals and fossil fuels (kg Sb equivalents/kg extraction). Antimony is a chemical element with symbol Sb.

(2) Acidification Potential (AP)

The contribution of Acidification potential impacts is the emission of corrosive gasses into the air like sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrochloric acid (HCL), hydrofluoric acid (HF) and ammonia (NH_4) which is taken up by climatic precipitations and subsequently causing acid raining. The contribution of relevant emissions is expressed in (H+) ion equivalents. Because of the wash-out of corrosive gasses, the rain is absorbed by plants, surface waters and soil, prompting harm and super acidity of the soil, with subsequently effect on natural environment. Life Cycle Impact Analysis Inventory (LCIAI), the effect of other acidifying emissions like NO_x, H_2S is given in the reference unit measure (SO_2 equivalents) which shows how much the equivalent of a given mass contributes to Acidification.

(3) Eutrophication Potential (EUP)

The contribution of significant outflows is indicated in PO_4 equivalent. Eutrophication is caused by too much large amounts of macro-nutrients, the most imperative of which are phosphorus (P) and nitrogen (N). The growth rate of algae in aquatic ecosystems increases and permits less daylight achieves further layers which led to less photosynthesis and inadequate oxygen. Subsequently, dead plants tumble down to further layers and degradation takes place. At long last, the inadequate presence of oxygen for fishes and other aquatic animals to survive and degradation process occur in the absence of oxygen and causes methane production.

(4) Global Warming Potential (GWP)

The temperature expansion of troposphere is because of greenhouse gases, example: from the consumption of petroleum derivatives, and the therefore emanation of CO_2. According with Intergovernmental Panel on Climatic Change (IPCC), GWP is measured in kg of CO_2 equivalent in life cycle assessment. This measures how much a unit mass of gas adds to Global warming potential contrasted with carbon dioxide. The gasses like carbon dioxide, nitrogen dioxide, methane, chlorofluorocarbons, hydro chlorofluorocarbons, and methyl bromide values are expressed in CO_2 equivalent. Time must always be expressed for specific time horizon index as 25, 100 or 500 years in GWP because the characteristic effect of greenhouse gases have different atmospheric lifetimes. In this study, the time horizon is 100 years.

(5) Ozone Layer Depletion Potential (ODP)

Another worldwide impact identified is Ozone layer depletion potential, which fundamental impact is the lessening of the ozone fixation in the stratosphere, because of emissions of chemicals, for example, Chlorofluorocarbons (CFCs) and Chlorofluorocarbons (HCFCs). In LCA, the reference substance for Ozone layer depletion potential is a measurement of the dangerous impacts of gasses on the ozone layer, measured in Tri-chloro-fluoro-methane-equivalent, R11-equivalent (Guinee, 2001). The ozone layer is shield against UV radiation to the earth and along these lines, anticipates inordinate warming of the earth's surface. Results of Ozone layer depletion incorporate the development of tumors in people and animals and in addition photosynthetic interruption in plants (Gabi tutorial clip 1, 2006).

(6) Human Toxicity Potential (HTP)

Human Toxicity Potential (HTP) evaluation intends to estimate the negative effect on people and the principle contributor are like heavy metals which is emitted to air, soil and water. The human potential toxicities produced from an extent in light of the reference substance 1,4-dichlorobenzene ($C_6H_4Cl_2$). For each toxic substance HTP’s are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale.

(7) Photochemical Oxidation (PO)

Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene (C_2H_4) equivalents/kg emission.

No weighting technique is installed into this strategy and the world (1995) year has been adopted as aggregate annual world interventions for the normalization factor. Importance of normalization is to examine the individual offer of each effect to the gross damage by applying normalization factors to midpoint or damage impact classes keeping in mind the end goal to encourage interpretation.

The initial step to frame a LCA of a WMS is to know the current situation of waste management system, waste quantity and its composition in Paro district.

Chapter 4

Results and discussion

4.1 Current scenario of solid waste management in Paro

In the light of worldwide waste circumstance, and in addition that of the local waste circumstances; present solid waste management in Paro is lacking, with improper disposal exercises showing tremendous potential risks to human well-being and nature. Despite the fact that sanitary landfill is the most well-known innovation around the globe, the current practices of the discarding method of waste in Paro district are neither environmentally effective nor financially viable where open-dumping, open-burning and open landfill are commonly practiced. Two specific challenges were transparent in the inappropriate waste framework; firstly, mixed waste being discarded in the open landfill without any segregation. Secondly, transportation of mixed waste without going through any treatment process and directly dumped in the open landfill. The present landfill has the capacity of 4,200 m^3 and it was built 11km away from the city of Paro in 2010 which is seven years ago. The waste collection organization concerned is not being able to handle with these waste issues totally even at the landfill.

Paro Municipality and "Druk Waste Collection" private limited are two responsible organizations for waste collection in Paro district. Both organizations collect solid waste from all the sources starting from households, industries, institutions, offices, shops, schools, road and building construction sites; collected waste dumped in open landfill with no separation and treatment. Aside from the waste collection, transporting and dumping in open landfill, scavenging exercises are additionally carried out in private waste collection sector. Meetings with solid waste management associations demonstrated that door to door waste collection and the waste collection in community steel waste bins of 1 m^3 capacity, which is situated at strategic intersections are two common types of waste collection practices. Paro Municipality has an exceptionally set number of equipment and facilities, with most of waste collection truck provided by the donor community. In the municipality, there is no transfer station and waste treatment facilities. Waste collection vehicles available in Paro municipality are one tipping truck with tipping mechanism, and two open trucks without tipping mechanism and two compactor vehicles with a capacity of 4 m^3, 5 m^3, and 6 m^3 respectively. The majority of these vehicles are old and worn, and progressively require more maintenance.

On the other hand, "Druk Waste Collection" has only single cabin bolero with a little tendency to carry waste of 2 m^3 capacity. Concerning the quick changes in the amount and composition of solid waste, this study strongly supports the observation that municipality must be in consistent discourse with service providers to enhance waste collection efficiency and solid waste management. The waste collection plan during the low season of tourism is two times a week and during the high tourist season is three times a week. On the other hand, the waste collection from the household unit is just one time a week throughout the seasons. The waste collection frequency isn't up - to the stamp as expected by the city tenants, which implies recurrence of waste collection every week should be expanded.

The waste composition at prompt source indicates significant waste components that would help in the viable source segregation of waste material to upgrade waste material recovery and develop integrated solid waste management plan. The major waste composition is an organic waste and some of the recyclable waste materials are collected by the scavengers from the community receptacle, and sell it to the recycling shop near Indian border which is 129 km away from the Paro region. Therefore, recyclable waste components, for example, glass bottles, plastic bottles, metal and cardboard boxes dumped in the community receptacles, in the street and in the landfill site are recognized as financial income to scavengers and also to some municipal workers at the landfill site. On the other hand, organic waste is identified as no financial incentive for waste authorities due to lack of facility.

There is no critical level of affiliation or relationship among or between the stakeholders proposing that there is no viable waste management framework. The current solid waste management framework in the Paro district is shown in Figure 4.1.

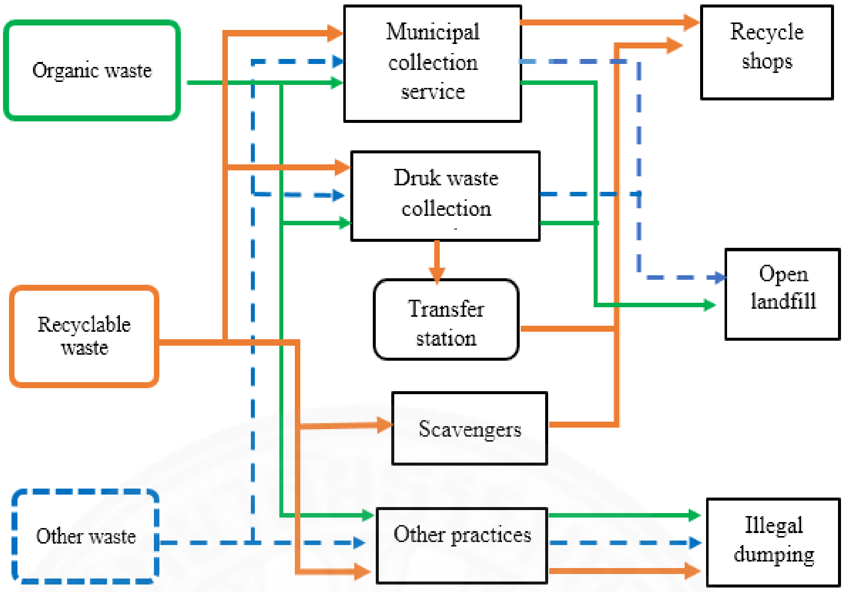


Figure 4.1 Current solid waste management system in Paro district

Some of the gaps found out through several data collection survey are listed below:

a. Gaps in hotel industries:

- No waste separation in most of the hotels, for example, the kitchen, restaurant, and bar, housekeeping, clothing, and maintenance waste.
- Less use of environmentally well-disposed materials. For instance, laundry bags are made of cloth (for soiled linen); and shampoo dispensed in ceramic bottles.
- Office stationery and paper are not reused.
- Shaded compartments like glass and plastic, paper and cardboard, polythene and plastic, and wet waste are only present in some of the 5-star hotels.
- Little practice of utilizing organic waste for composting and donating food waste to the pig farms.

b. Gaps in household units:

- Lack waste segregation at source.
- Less enthusiasm for taking an interest on waste management programs like mass city cleaning campaign due to lack of common social syndrome known as “ NOT IN MY BACKYARD”.

- Inadequate practice of recycling organic waste for composting at home
- Little knowledge/awareness on solid waste management.
- Dumping waste on the open spaces, burning and disposing waste along the river side and roads are common practices.

c. Gaps in responsible agency:

- Lack of financial support.
- Inadequate cooperation between the public and responsible organization
- Lack of skilled officers.
- Lack of research work on solid waste generation, compostion and management.
- Lack of study on environmental impact assessment of current solid waste management system.

4.2 Waste generation and composition in hotel industry

4.2.1 Waste generation in hotel industry

Based on this study, the total amount of 64,061 kg of solid waste collected from all the sources is sent to the landfill every day in Paro district. The total number of registered hotels in Paro district is 30 with 883 total rooms based on the tourism council of Bhutan. The information on the total number of rooms for all the selected hotels was collected through a questionnaire survey. However, due to confidential information, the total number of occupancy in each hotel was estimated from the total number of rooms in the hotel. The assumption had been made that 70% of the total hotel rooms are occupied since the October month is the peak season for the tourism in Bhutan. Based on this assumption, it was estimated that there are total 618 tourists in 883 rooms of hotel. The total waste generated from hotel industry is 494 kg per day and 0.8 kg per capita per day as shown in Table 4.1.

Table 4.1 Waste generated per capita per day in hotel industry

Hotels	Total number of rooms	Occupancy (70% of total rooms)	Waste generation quantity (kg) Min - Max	Average waste generated per day (kg)	Average waste generated per capita per day (kg)
5 stars	104	73	94-235	159	2.2
4 stars	117	82	16-60	38	0.5
3 stars	77	54	25-42	47	0.9
2 stars	200	140	22-36	33	0.2
1 star	147	103	22-36	29	0.3

The total amount of waste generated from day to day is significantly different as shown in Figure 4.2. The waste generation per day is different in both same category and different hotel category hotels. The difference in the results between different hotel categories and within the same hotel categories might be because of number of tourist, nationality and income. The average waste generated from day 1 to day 7 study demonstrated that total waste generated in hotels are directly proportional to the number of occupancy.

1-star hotel consists of 5 hotels and the waste generated is 0.2 to 0.3 kg/guest per day. Six hotels in 2-star hotel generates 0.17 to 0.35 kg/guest per day of waste and followed by 2 hotels in 3-star hotel generates 0.6 to 1.2 kg/guest per day. However, from the 3 hotels in 4-star hotel generate 0.2 to 0.7 kg/guest per day as some of these hotels practices composting of food waste and donating food waste to pig farming. From the 2 hotels in 5-star hotel generates 1.3 to 3.2 kg/guest per day. The main reason of generating more waste in 5-star hotels is due to involvement of various activities such as cultural activities for tourist, conference, marriage party, fashion shows, meetings and workshops.

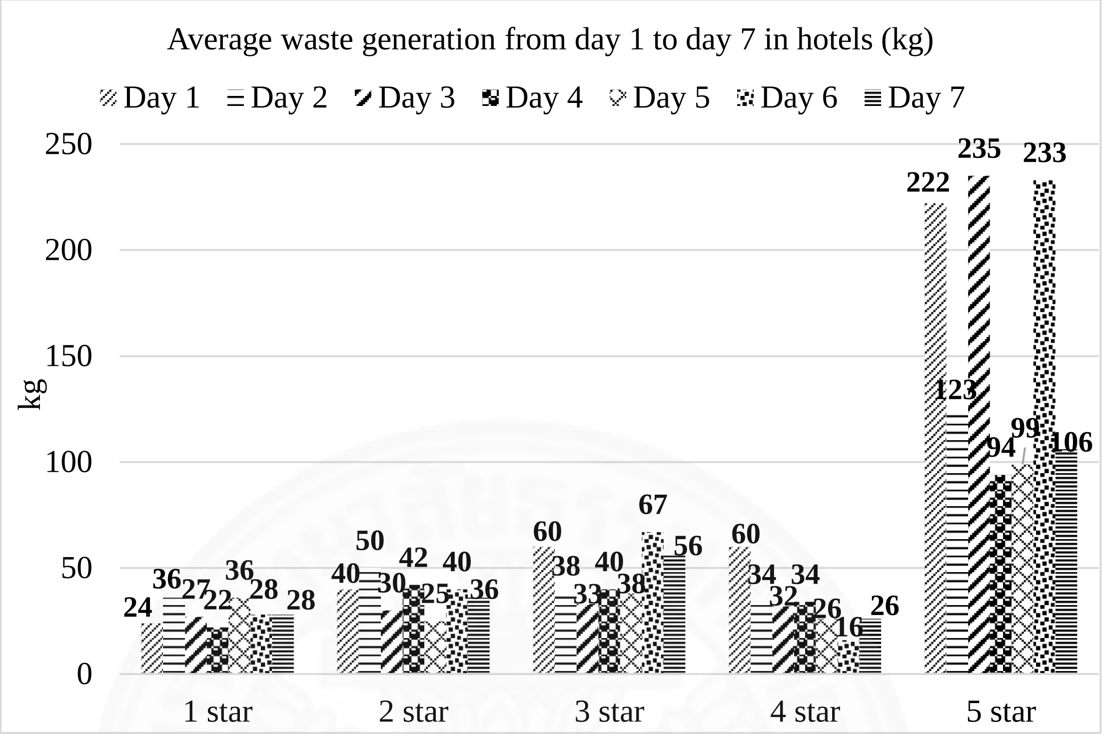


Figure 4.2 Average waste generated from in hotel industry from day 1 to day 7

The similar results of weekly waste generation variance are obtained by using ANOVA analysis with significant average differences as shown in Table 4.2.

Table 4.2 ANOVA analysis for weekly variation

ANOVA: Single Factor						
Groups	Count	Sum	Average	Variance		
1 star	7	201	28.71	29.57		
2 stars	7	263	37.57	67.29		
3 stars	7	332	47.43	175.95		
4 stars	7	228	32.57	186.29		
5 stars	7	1112	158.86	4525.14		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	85117.54	4	21279.39	21.35	2.0289E-08	2.69
Within Groups	29905.43	30	996.85			
Total	115022.9714	34				

There is a statistically significant difference in waste generation between different hotel category and even within a similar hotel category as dictated by ANOVA test (F>Fcrit) at 0.05 level of significance.

4.2.2 Waste composition in hotel industry

In general, the hotel waste composition includes both dry waste and wet waste (biodegradable). Solid waste from Paro hotel comprises of eatery sustenance waste, office paper, tissue paper, bottles, plastic, glass, aluminum refreshment compartments, and cardboard boxes. During the in-depth interviews with hotel managers, they were asked on waste separation practices information and it was discovered that there is a deficient waste separation at source with no predefined framework. For instance, 5-star hotels have three unique compartments to collect glass, plastic, and paper, whereas in some 1-star and 2-star hotel collect glass and metal and sell them to waste dealers. Somewhere in the range of 3 and 4-star lodgings have just two compartments for dry waste and wet waste. The level of waste creations in various sorts of inns are appeared in Table 4.3.

Table 4.3 Waste composition in different hotel categories

Composition (%)	Hotel ratings					Average waste composition in hotel (%)
	5 star	4 star	3 star	2 star	1 star	
Food waste	60	42	56	44	62	53
Glass	12	17	12	18	14	14
Paper	7	10	8	10	8	9
LDPE	7	9	7	8	6	7
Textiles	3	6	6	5	3	5
Metal	7	8	7	9	3	7
HDPE	1	4	3	3	2	3
Rubber	1	1	1	2	0	1
Others	1	2	1	0	1	1
Garden	1	0	0	0	1	0
Leather	0	1	0	1	0	0

Organic waste is the most astounding waste commitment from waste stream with a average rate extending from 42-62%. Glass contributes as the second highest with an average rate extending from 12-18% followed by other sorts of waste like paper, metal, LDPE, textiles, HDPE, rubber, and others.

4.3 Waste generation and composition in household units

4.3.1 Waste generation in household units

Paro is one of the major city in the western part of Bhutan with a population of 43,167 with 7,118 households based on 2015 statistical data. In view of this information, an estimation has been made that an average waste generated from household sampled is 7.5 kg per day and an average waste generated per capita per day is estimated at 0.5 kg which is shown in Table 4.4. The total amount of waste generated per day from the household is 22 tons based on total number of population. And approximately 64 tons of total municipal solid waste are sent to the landfill every day, including household waste without any waste treatment and source segregation.

Table 4.4 Average waste generated per capita per day from 20 household units

Location of households	Number of people in 4 households/ location	Average waste generated per day (kg) in 4 households	Waste generated per capita/day (kg)
Shaba	17	8.8	0.5
Geptey	16	8.3	0.5
Paro town	18	9.3	0.5
Gantey	15	6.2	0.4
Olathang	14	5.0	0.4
Average	16	7.5	**0.5 kg**

The waste generation rate per head is different between total number of household members and different localities. The relationship between waste generated per day and number of people is shown in the Figure 4.3. It demonstrates that the highest family members in aparticular area produced the highest amount of waste per day and vice versa. As stated by numerous researcher, this clearly shows that expansion in population in particular area causes an expansion in waste generation subsequently.

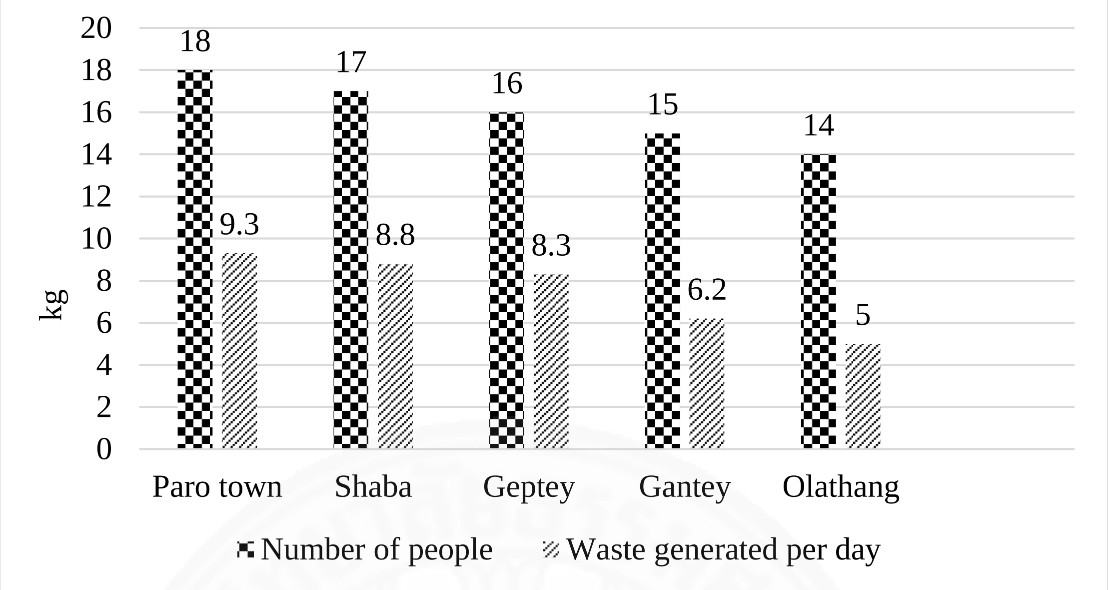


Figure 4.3 Relationship between number of people and waste generation rate

4.3.2 Waste composition in household units

The primary reason of household waste composition study was to find the difference of waste composition generated by the local people when it is compared with the hotel industries. The amount of solid waste generated from the household demonstrates that 48% of highest food waste composition followed by paper with 12%, soft plastic like LDPE with 10%, textiles and glass with 8%, rubber with 6%, metal with 4%, HDPE with 3%, others with 1 %, garden waste and leather with 0% as shown in Figure 4.4.

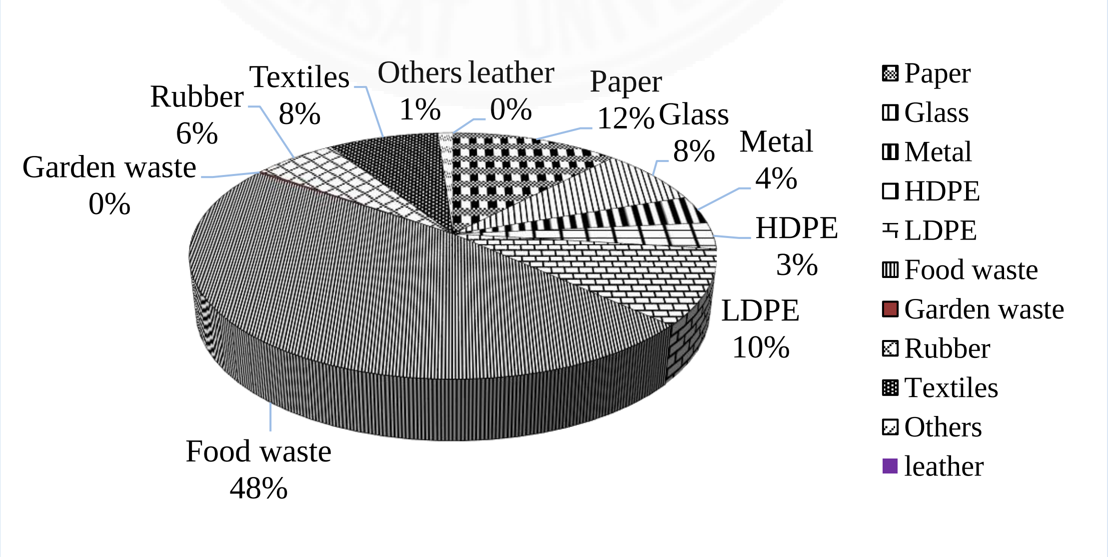


Figure 4.4 Waste composition in household units

4.4 Comparison of waste composition two sectors

The waste composition quantity in the household unit is little different from the hotel waste generated in the month of October. However, the large volume of organic waste is one of the most notable characteristics of waste composition study in both household units and hotel industries in Paro district. Organic waste generated in hotel industries needs to be reduce more when it is compared with organic waste in household units. Similarly, the recyclable waste materials such as an empty beer bottles and wine bottles are mostly generated in the hotel industries when it is compared with household units. However, there is not much differene in the percentage of other types of waste generated between household units and hotel industries as shown in Figure 4.5.

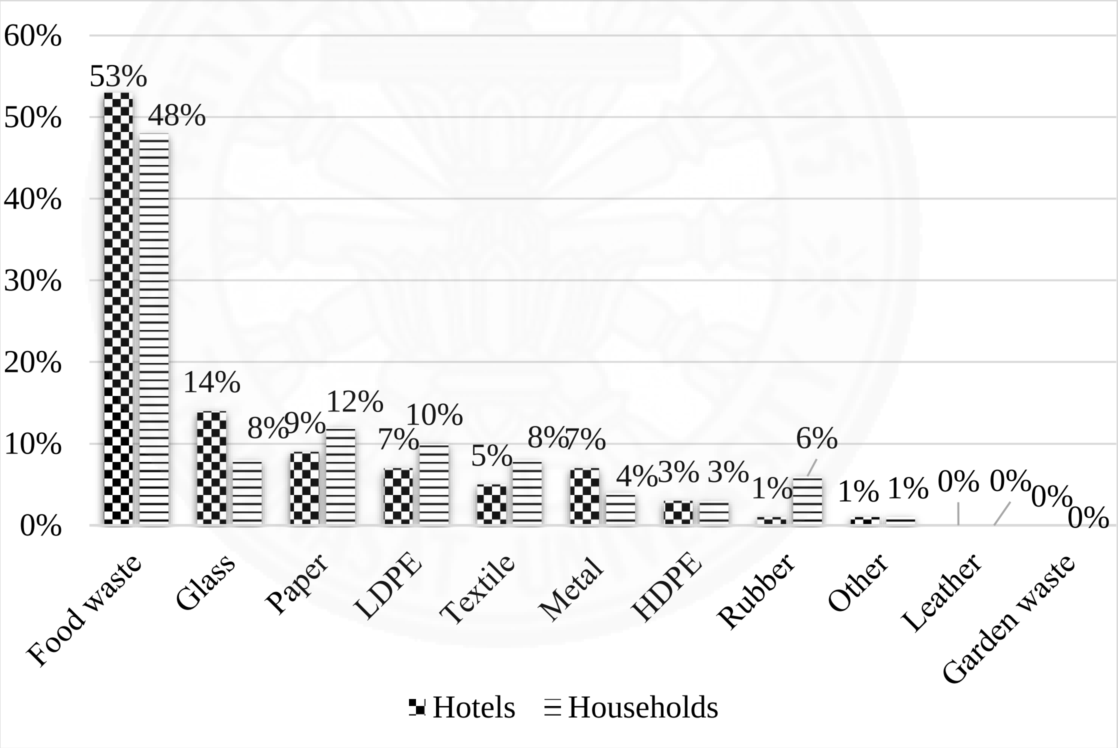


Figure 4.5 Comparison of waste composition between two sectors

The average of paper and cardboard boxes generated from the household and hotel sector comprises around 10.5% of the total solid waste generated. Paper are treated as a normal waste in Paro by disposing in the landfill due to absent of paper recycling plant and some are burn at source. Combining both plastic bags and PET bottles constitute of 11.5% of the total waste generated from both hotels and households. Typically, plastic packs are likewise dumped in the landfill with no separation and treatment. Recyclable waste materials which are collected and sold across Indian recycling shop are glass bottles, metals, aluminum cans, cardboard boxes, and PET containers. The high density of cardboard boxes, aluminum/metal containers and PET bottels may increases the waste transportation service expenses from Paro to Indian border without crushing it due to absent of compressing machines causing environmental pollution from the transportation sector.

Currently, generation of solid waste in lodging enterprises has higher probability to diminish, for instance by reusing clothing sacks, towels, dustbins, cleanser and conditioner bottles. If all the hotels involved in composting practices, 50 percentage of food waste might be reduced in hotel industries. Table 4.5 demonstrates an average waste composition in 2007 and 2016 to show some brief background of solid waste composition in Paro district and to compare the results among those years. Ten urban districts of Bhutan were included in the national waste composition in 2007 study. The current study of waste composition is the average waste composition from hotel and household sectors.

Table 4.5 Waste composition in 2007 and 2016

Waste composition	Food	Glass	Paper	HDPE and LDPE	Metal	Textile	Leather	Rubber	Other
Average of this study, 2016	50%	11%	11%	12%	5%	6.5%	0%	3.5%	1%
Average (Paro, 2007)	58%	5%	14%	15%	1%	3%	3%	_	1%
Average (National, 2007)	58%	4%	17%	13%	1%	2%	2%	_	3%

There are no changes in solid waste composition in the Paro district from 2007 to 2016. However, there is a little difference in percentage of solid waste components between these two years. From 2016 study, the percentage of waste components like glass, metal, rubber and textiles is increased and this shows some way or another that living style in Paro is evolving. Example, purchasing goods and spending attitudes show that Paro is shifting from traditional society to modern society. On the other hand, the percentage of some of the recyclable waste is reduced from 2007 to 2016. This reduction result shows that the current waste management system in Paro is somehow in the stage of developing procedure when it is compared with the year of 2007. This is because the recycling activity was not there yet, so the amount of recyclable materials entered in the landfill was higher.

4.5 Factors influencing solid waste management in Paro district

4.5.1 Legislation and policy

The establishement quality of municipal solid waste management is powerless and inadequate. Additionally usage of this approach is not observed. The policy is not all around organized and unquestionably has a tendency to be powerless: take an example of plastic bag which has been banned however, there is still the usage of plastic bags. There are no specific regulations, develop particularly for solid waste like hazardous and medical waste management system.

4.5.2 Financial

The waste management is not given top priority because of less financial support provided by the government. Poor quality of waste collection vehicle, no financial support for its mending and causing less services. Budgetary help to local municipalities by the government is extremely essential for waste transportation to a transfer station/landfill site, for promoting recycling facilities and programs. Modern equipment for waste management system is expensive and may even be costlier for its maintenance. Inadequacy of obtaining new waste collection trucks, waste receptacles, equipments, rectycling facility and construction of transfer station. Most of the waste collection vehicles are donated by foreign donor agency.

4.5.3 Level of waste awareness

Intensive education and training of occupants of the city is required to guarantee they completely comprehend the impact of the environment and human health caused by insufficient MSW management which will enhance their motivation in paying waste management services (Asase et al., 2009). Public awareness on sustainable solid waste management system is still extremely poor and exertion by the waste collection organization to promote waste awareness is still low in Paro district. Workers in the organization are not very much educated on the unfriendly impacts of unpredictable and disgraceful disposal of waste and furthermore the advantages of such act. The low level of waste awareness is causing lack of public participation and stakeholders. Therefore, due to lack of dynamic help from a country's organization, private stakeholders for public awareness program impacts the waste separation altitudes in the household units.

4.5.4 Infrastructure

The responsible waste collection individuals are not specialists and presented to workshops and training that meet international standards on application of technology, conducting research work on solid waste and reporting feasible information. Most of the recycling materials are transported to India due to lack of recycling technology. Municipal solid waste in Bhutan has risen informal disposal because of inadequate waste collection plan, lack of feasible data and appropriate policy framework. Data on waste generation, collection and composition from all the district of Bhutan is not available so that to develop reliable database and effective waste management framework. Moreover, Hazra and Goel (2009) reported that poor collection system is mainly due to improper receptacle collection frameworks, inadequate transportation planning and absence of collection planning information (Hazra and Goel, 2009).

4.5.5 Waste disposal method

Informal disposal cause an unfriendly effect on all parts of the natural environment and human well being (Chandra and Linthoingambi Devi, 2009). The most common practices of disposal is open dumping system of waste materials without any treatment processes which could cause threats to public health and environmental damages including climate change. Burning combustible waste near household, dumping waste in the river and open spaces are some of the improper practices of waste disposal. It is an essential to know the environmental burden from the current waste management system and from the alternatives waste management approaches during waste management plan. This information can be used to aid decision making process when the improvement of the SWM system is needed.

4.6 Environmental Impact Analysis

4.6.1 Major emission substances

The main caused of environmental burden is from the process of waste management system. The average annual impact of a world in the year 1995 is selected for normalize method. Generally, the emission results are presented in “per year” unit for substance emissions. From the background of alternative waste treatment analysis, some of the major emissions to water and air are shown in Table 4.6 and Table 4.7 with the major contribution process of emissions are shown in Table 4.8.

Table 4.6 Life Cycle Inventory of alternative scenarios (air emissions)

Substances	Scenario-0	Scenario-1	Scenario-2	Scenario-3	Scenario-4
CH_4	3.50E-11	4.64E-12	3.50E-11	2.80E-11	2.10E-11
CO_2	5.06E-12	5.86E-13	-3.13E-09	-6.37E-11	-1.32E-11
N_2O	6.12E-14	2.18E-14	3.31E-12	2.60E-12	1.90E-12
NOx	2.68E-11	1.729E-13	-4.75E-11	-2.07E-11	-4.52E-11
SO_2	6.01E-12	4.96E-12	-1.25E-10	-5.99E-11	-1.26E-10
HF	1.83E-14	1.83E-14	-1.78E-12	-8.82E-13	-1.78E-12
HCl	1.47E-15	1.47E-15	-6.23E-15	-2.38E-15	-6.23E-15
NH_4	5.45E-21	5.14E-22	5.45E-21	4.24E-21	3.04E-21
Total heavy metals	1.78E-13	2.795E-15	-6.80E-13	-3.19E-12	-6.55E-12
Total NMVOC	1.35E-12	1.18E-12	-1.55E-12	-1.81E-13	-1.74E-12
Total	**7.45E-11**	**1.16E-11**	**-3.27E-9**	**-1.18E-10**	**-1.72E-10**

Table 4.7 Life Cycle Inventory of alternative scenarios (water emissions)

Substances	Scenario-0	Scenario-1	Scenario-2	Scenario-3	Scenario-4
COD	6.91E-11	6.91E-11	3.36E-11	5.14E-11	3.36E-11
N	2.20E-13	2.08E-14	-3.54E-13	-6.14E-14	-3.43E-13
NH_3	8.95E-12	3.84E-12	8.95E-12	7.20E-12	5.44E-12
P	9.60E-16	9.05E-17	-3.74E-13	-1.86E-13	-3.73E-13
PO_4	1.23E-11	1.16E-12	-4.53E-11	-1.89E-11	-5.00E-11
Total heavy metals	3.67E-12	2.96E-12	-6.8E-13	2.0E-12	3.3E-13
Total	**9.42E-11**	**7.71E-11**	**-4.16E-12**	**4.15E-11**	**-1.14E-11**

Note: Negative values represent an advantage in environmental terms because impacts are avoided.

Table 4.8 Major contribution of substance emissions from different processes

Impact category	Process contribution	Substances
Abiotic depletion potential	Transportation of solid waste and food waste treatment of sanitary landfill	Energy from fossil fuel, CH_4 and CO_2
Acidification potential	Bio-waste composting and food waste treatment of sanitary landfill	SO_2, NOx, N_2O, NH_3 and HCl
Eutrophication potential	Food waste, polyethylene terephthalate and textile waste treatment of sanitary landfill	PO_4, NH_4, NH_3, N, P, N_2O and COD
Global warming potential	Food waste, paper waste and textile waste treatment of sanitary landfill	CO_2 and CH_4
Ozone layer depletion	Food waste treatment of sanitary landfill and transportation of solid waste	CO_2 and CH_4
Human toxicity potential	Polyethylene terephthalate and polyvinyl-chloride waste treatment of sanitary landfill	Metals, HCl, HF, N_2O, and NO_x
Photochemical oxidation	Food waste, textile waste and paper waste treatment of sanitary landfill	NMVOC

The highest CH_4 emission is emitted by Scenario-0 and Scenario-2 with 3.50E-11 kg per year. This emission is mainly caused due to treatment of food, paper and textile waste in the sanitary landfill, which basically led to Global warming, Photochemical oxidation and Ozone layer depletion (CH_4 emissions from transportation process and from decomposition process). Scenario-0 also emitted highest CO_2 (fossil), N_2O, NO_x, SO_2 and total metals when it is compared with other scenarios causing high potential on Acidification, Human toxicity and Global warming from CO_2 (fossil) emission. Air emission substances in Scenario-4 is reduced drastically from the Scenario-0 due to reduction of food waste in the landfill. Regarding water emissions between alternative scenarios, the highest emission of COD (Chemical Oxygen Demand) is from Scenario-0 and Scenario-1 with 6.91E-11 per year.

4.6.2 Environmental impact performance

The result of comparative characterization is shown in Figure 4.6 to Figure 4.12. The relative score ranged from 0% to 100% in comparative characterization; the lower the score, the better the environmental performance. Environmental burden included in this study are Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Ozone Layer Depletion Potential (ODP), Eutrophication Potential (EU), Photochemical Oxidation (PO), Acidification Potential (AP) and Human Toxicity Potential (HTP).

4.6.2.1 Abiotic Depletion Potential (ADP)

The main contribution of Abiotic depletion is from disposing food waste in the landfill as shown in Table 4.9. Abiotic depletion potential impact increase in response to decrease in the level of composting and recycling. Abiotic depletion is usually linked with the consumption of natural resource. Recycling waste materials can be utilized to supplant virgin materials, conceivably resulting in saving energy consumption, raw materials, and reducing pollution. Scenarios that implement recycling of recyclable materials has a benefit to Abiotic depletion potential with negative result. Transportation process contribution of Abiotic depletion potential for all the scenarios are same due to same distance assumption.

Table 4.9 Major contribution process of Abiotic Depletion Potential

Process	Unit	S-0	S-1	S-2	S-3	S-4
Total of all processes	kg Sb equivalent	0.4	0.4	-4.9	-2.9	-5.0
Landfill of food waste	kg Sb equivalent	0.3	0.1	0.3	0.2	0.1
Remaining processes	kg Sb equivalent	0.1	0.3	-5.2	-3.1	-5.1

The results of Abiotic depletion from Scenario-0 to Scenario-4 are 9.44%, 7.52%, -

98.1%, -45.3% and -100% respectively as shown in Figure 4.6.

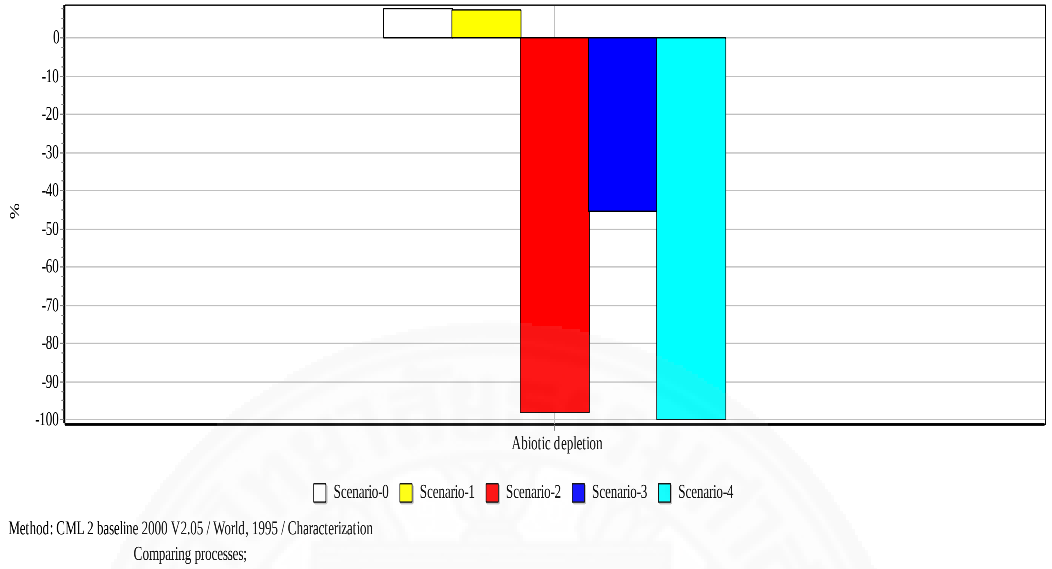


Figure 4.6 Abiotic Depletion Potential results for Scenario 0-4

4.6.2.2 Acidification Potential (AP)

Acidification alludes to processes that cause an expansion of acidity in water and soil quality. Important acidifying potential emission substances in this study are NO$_x$, SO$_x$, NH$_3$, HCl, etc., prompt to deposition, which thus can harm to animal and plant populaces. Landfilling and composting practices have a more impact on water quality due to production of hydrochloric acid.

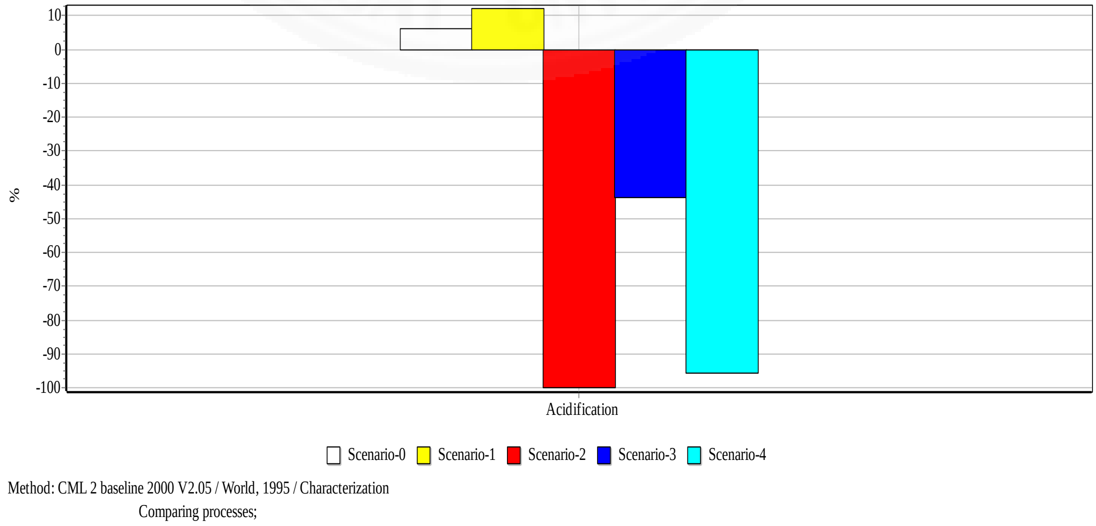


Figure 4.7 Acidification Potential results for Scenario 0-4

The Acidification impact contributes mostly from the landfilling of food waste and composting of bio-waste (shown in Table 4.10) which has potential to increase the heavy metal impact. Scenario-2 is the best scenario for this impact category with -100% potential followed by Scenario-4 with -95.6% of impact potential due to absent of composting activity and recycling 50% of recyclable materials. On the other hand, Scenario-0 has relatively higher Acidification potential with 7.77% due to lack of recycling activity. In Scenario-1 and Scenario-4 has a same contribution from the composting activity with 0.3 Kg SO_2 equivalent followed by 0.1 Kg SO_2 equivalent in Scenario-3. Similarly, the contribution in Scenario-0 and Scenario-2 where the composting activity is not included has maximum impact from landfilling food waste when it is compared with other scenarios. Overall, Scenario-2 (recycling 50% of recyclable materials) has the lowest impact on acidification potential due to reduction of NH_3 from biological processes.

Table 4.10 Major contribution process of Acidification Potential

Process	**Unit**	**S-0**	**S-1**	**S-2**	**S-3**	**S-4**
Total of all processes	kg SO_2 equivalent	0.3	0.5	-4.2	-2.0	-4.0
Bio-waste composting	kg SO_2 equivalent	-	0.3	-	0.1	0.3
Landfilling food waste	kg SO_2 equivalent	0.2	0.1	0.2	0.1	0.1
Remaining processes	kg SO_2 equivalent	0.1	0.1	-4.4	-2.2	-4.4

4.6.2.3 Eutrophication Potential (EUP)

From the comparative characterization result, the significant impact category in all waste treatment scenarios is eutrophication potential. The main pollutants causing eutrophication are phosphate (PO_4), ammonium (NH_4), ammonia (NH_3), nitrogen (N), phosphorus (P), Nitrogen dioxide (N_2O) and Chemical Oxygen Demand (COD). Primary effects are transportation and leachate from landfill which is more perilous for the water and soil quality due to degradation of solid waste in the landfill. The contribution process of Eutrophication potential in this study is from the landfill as shown in Table 4.11.

Table 4.11 Major contribution process of Eutrophication Potential

Process	**Unit**	**S-0**	**S-1**	**S-2**	**S-3**	**S-4**
Total of all processes	kg PO_4--- equivalent	2.5	2.0	0.9	1.3	0.4
Landfill of food waste	kg PO_4--- equivalent	1.2	0.6	1.2	0.9	0.6
Landfill of polyethylene terephthalate	kg PO_4--- equivalent	0.4	0.4	0.2	0.3	0.2
Landfill of paperboard	kg PO_4--- equivalent	0.3	0.3	0.1	0.2	0.1
Remaining processes	kg PO_4--- equivalent	0.6	0.7	-0.6	-0.1	-0.5

The major eutrophication impact contribution is from landfilling 100% of food waste in Scenario-0 and Scenario-2 with 1.2 kg PO_4--- equivalent followed by Scenario-3 with 0.9 kg PO_4---equivalent due to composting only 25% of food waste. Another maximum impact contribution is from landfilling polyethylene terephthalate in Scenario-0 and Scenario-1 with 0.4 kg PO_4---equivalent when it is compared to other alternative situation. Similarly, maximum eutrophication burden from landfilling paperboard in Scenario-0 and Scenario-1 is same with 0.3 kg PO_4--- equivalent due to disposing same amount of paperboard in the landfill. The characterization result for Eutrophication potential impact in each Scenario is shown in Figure 4.8.

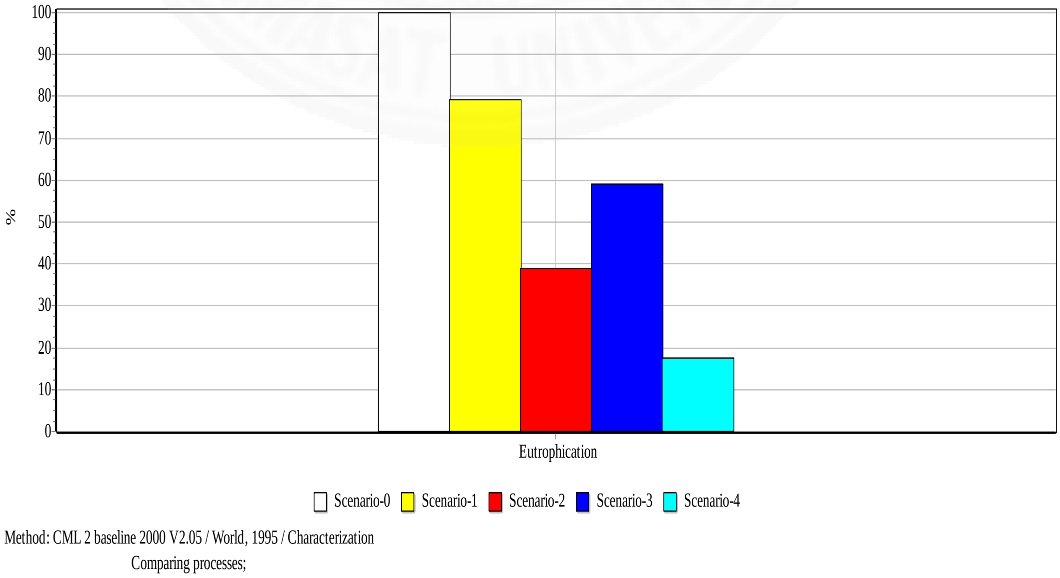


Figure 4.8 Eutrophication Potential results for Scenario 0-4

Overall, Scenario-2 and Scenario-4 contributes less impact because of recycling 50% of recyclable waste materials. Positive impact of recycling for Eutrophication potential is reduction of leachate containing NH_3, NO_x, P and N from organic waste. Composting enhances downstream water quality by preventing pollutants, for example, heavy metals, nitrogen, and phosphorus.

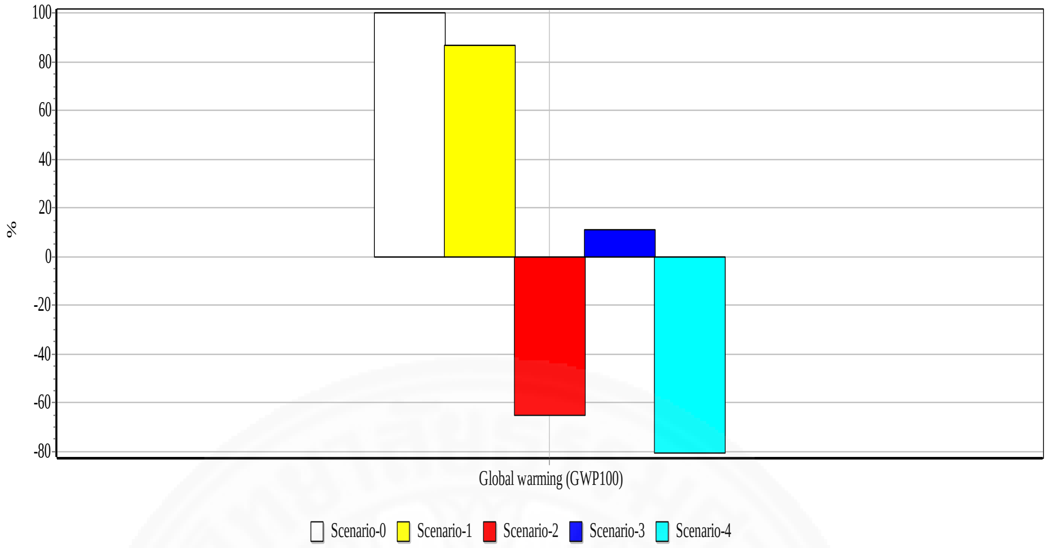
4.6.2.4 Global Warming Potential (GWP)

The scenarios of GWPs from the explored LCAs range from -408.2 to 505.4 kg CO_2 equivalents emitted per ton of solid waste treated. The largest anthropogenic source of atmospheric methane is the landfill. Landfill gas is a significant contributor to atmospheric methane and this production is a great concern as a great effect on greenhouse impact. In this study, the major contribution of Global warming is from landfilling biodegradable waste, paper board and textile waste as shown in Table 4.12.

Table 4.12 Major contribution process of Global Warming Potential

Process	**Unit**	**S-0**	**S-1**	**S-2**	**S-3**	**S-4**
Total of all processes	kg CO_2 eq.	505.4	439.3	-328.6	55.2	-408.2
Landfill of food waste	kg CO_2 eq.	245.2	122.6	245.2	183.9	122.6
Landfill of paperboard waste	kg CO_2 eq.	119	119	59.5	89.3	59.5
Landfill of textiles	kg CO_2 eq.	55.7	55.7	55.7	55.7	55.7
Remaining processes	kg CO_2 eq.	85.5	142	-689	-273.7	-646

Scenario-0, Scenario-1, and Scenario-3 has a higher potential for Global warming impact when it is compared to Scenario-2 and Scenario-4 due to a larger fraction of food waste and recyclable waste material disposed in the landfill. In spite of the fact that methane and carbon dioxide are produced in practical parallel amounts in landfills, methane is 21 more than carbon dioxide. It was discovered that critical diminished of Global warming is related with expanding levels of recycling and the highest amount evaluated is recycling of 50% recyclable waste in Scenario-2 and Scenario-4.



Method: CML 2 baseline 2000 V2.05 / World, 1995 / Characterization
Comparing processes;

Figure 4.9 Global Warming Potential results for Scenario 0-4

Global warming impacts fall by 10% with an addition of composting 50% of food waste in scenario-1 as shown in above Figure 4.9. Furthermore, increasing levels of recycling of recyclable waste material as the most elevated advantages for Global warming in this study. Recycling reduces the emission of chemicals and greenhouse gasses from the landfill sites and reduces the consumption of natural resources. Therefore, the landfilling situation is the worst option for Global warming.

4.6.2.5 Ozone Layer Depletion Potential (ODP)

Primary contribution from transportation of municipal solid waste because of CO, NMVOCs and VOCs emissions. Contribution impact of the transportation process in all the scenarios are same due to the same distance assumption. Table 4.13 shows the major contribution of Ozone layer depletion potential in this study.

Table 4.13 Major contribution process of Ozone Layer Depletion Potential

Process	**Unit**	**S-0**	**S-1**	**S-2**	**S-3**	**S-4**
Total of all processes	kg CFC-11 eq.	3.2E-6	5.6E-6	-2.7E-5	-1.1E-5	-2.7E-5
Transportation service	kg CFC-11 eq.	2.6E-6	2.6E-6	2.6E-6	2.6E-6	2.6E-6
Landfilling of food waste	kg CFC-11 eq.	1.4E-6	7.0E-7	1.4E-6	1.0E-6	7.0E-7
Landfilling of paperboard waste	kg CFC-11 eq.	3.5E-7	3.5E-7	1.8E-7	2.7E-7	1.8E-7
Remaining processes	kg CFC-11 eq.	-1.2E-6	2.0E-6	-2.9E-5	-1.2E-5	-2.8E-5

Landfilling of biodegradable waste (paperboard and food waste) has the major contribution in Ozone layer depletion for all the scenarios due to emission of methane gas. Scenario-0 and Scenario-1 shows the highest Ozone layer depletion impact potential with 11.9% and 20.9% respectively as shown in Figure 4.10. Therefore, increasing the level of composting for food waste and the level of recycling for paperboard waste as the most elevated advantages/reduction for Ozone layer depletion.

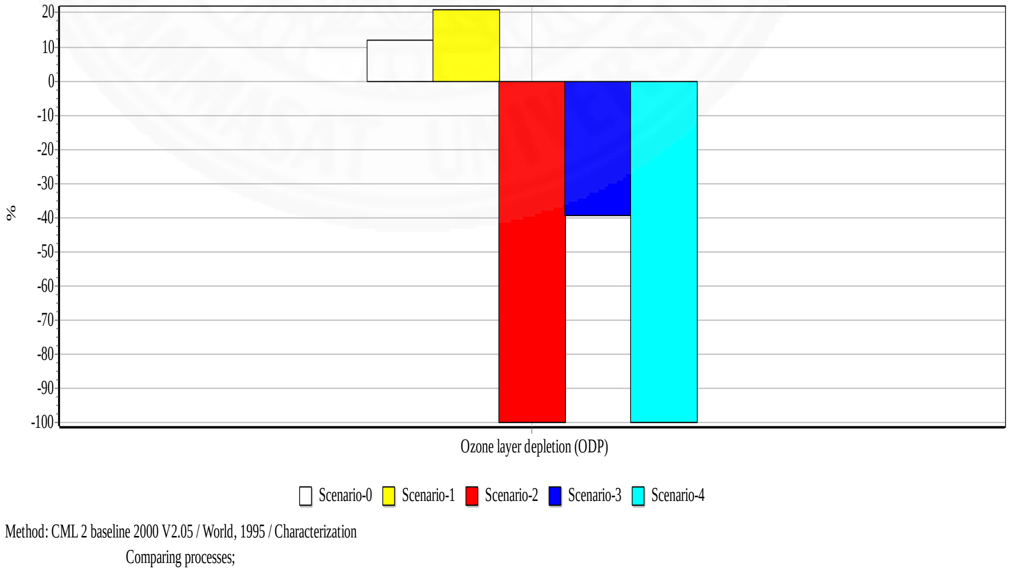


Figure 4.10 Ozone Layer Depletion results for Scenario 0-4

Landfilling biodegradable waste generates methane gas, which is a potent greenhouse gas. By composting biodegradable waste reduces methane emissions. Extraction of natural resources, processing and transportation of virgin materials is avoided in recycling system which reduces resource consumption and emissions. Combustion is the net producer of energy which this offsets energy produced from utilities.

4.6.2.6 Human Toxicity Potential (HTP)

The outcomes from the 5 scenarios with Human toxicity potential ranges from -1053.9 to 196.8 kg 1,4-DB equivalents per ton of solid waste treated. Human toxicity potential is caused by Metals (air and water emission), HCl, HF, N_2O, NO_x emissions from polyethylene terephthalate and polyvinyl chloride treatment of a sanitary landfill. Major contribution sources of Human toxicity potential in this study is shown in Table 4.14. Result demonstrates that the increasing level of landfilling polyethylene terephthalate and polyvinyl chloride waste causes the most elevated disadvantages of Human toxicity and vice versa. The major impact related with plastics waste is that plastics don't degrade, and they endure for longer period representing a hazard to human health while recycling activity reduces impact on human health and reduces the consumption of natural resources required to make virgin plastics.

Table 4.14 Major contribution process of Human Toxicity Potential

Process	Unit	S-0	S-1	S-2	S-3	S-4
Total of all processes	kg 1,4-DB eq.	196.8	198.7	-1053.9	-427.6	-1053.9
Landfilling of Polyethylene terephthalate waste	kg 1,4-DB eq.	128.7	128.7	64.3	96.5	64.3
Landfilling of polyvinyl chloride waste	kg 1,4-DB eq.	17.4	17.4	8.7	13.0	8.7
Remaining processes	kg 1,4-DB eq.	50.7	52.6	-1126.9	-537.1	-1126.9

The highest contribution of Human toxicity is from Scenario-0 and Scenario-1 when compared other scenarios as shown in Figure 4.11.

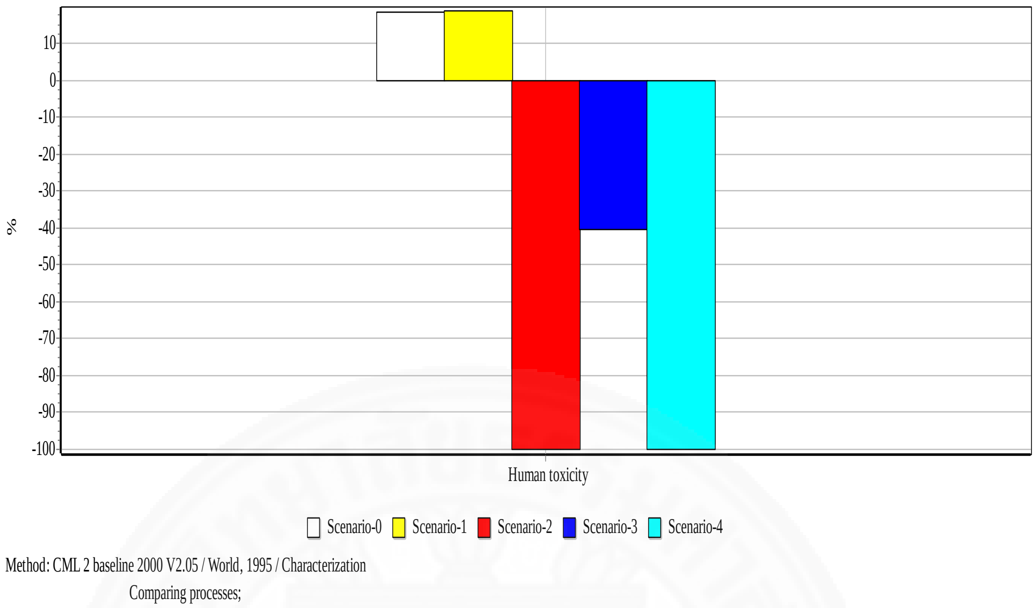


Figure 4.11 Human Toxicity Potential results for Scenario 0-4

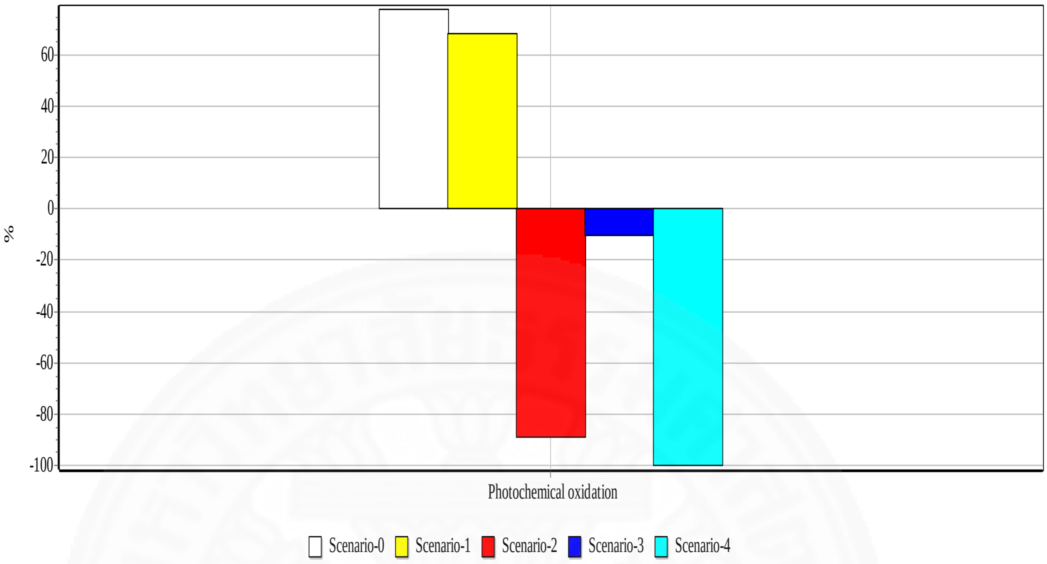
4.6.2.7 Photochemical Oxidation (PO)

The landfill has the most astounding Photochemical oxidation potential than other scenarios because of NMVOC emissions. The primary contribution of these emissions is due to landfilling food waste and paperboard as shown in Table 4.15.

Table 4.15 Major contribution process of Photochemical Oxidation Potential

Process	Unit	S-0	S-1	S-2	S-3	S-4
Total of all processes	kg C_2H_4 eq.	0.1298	0.1139	-0.1488	-0.0174	-0.1671
Landfilling of food waste	kg C_2H_4 eq.	0.0560	0.0280	0.0560	0.0420	0.0280
Landfilling of paperboard waste	kg C_2H_4 eq.	0.0361	0.0361	0.0181	0.0271	0.0181
Landfilling of textiles	kg C_2H_4 eq.	0.0130	0.0130	0.0130	0.0130	0.0130
Remaining processes	kg C_2H_4 eq.	0.0247	0.0368	-0.2359	-0.0993	-0.2259

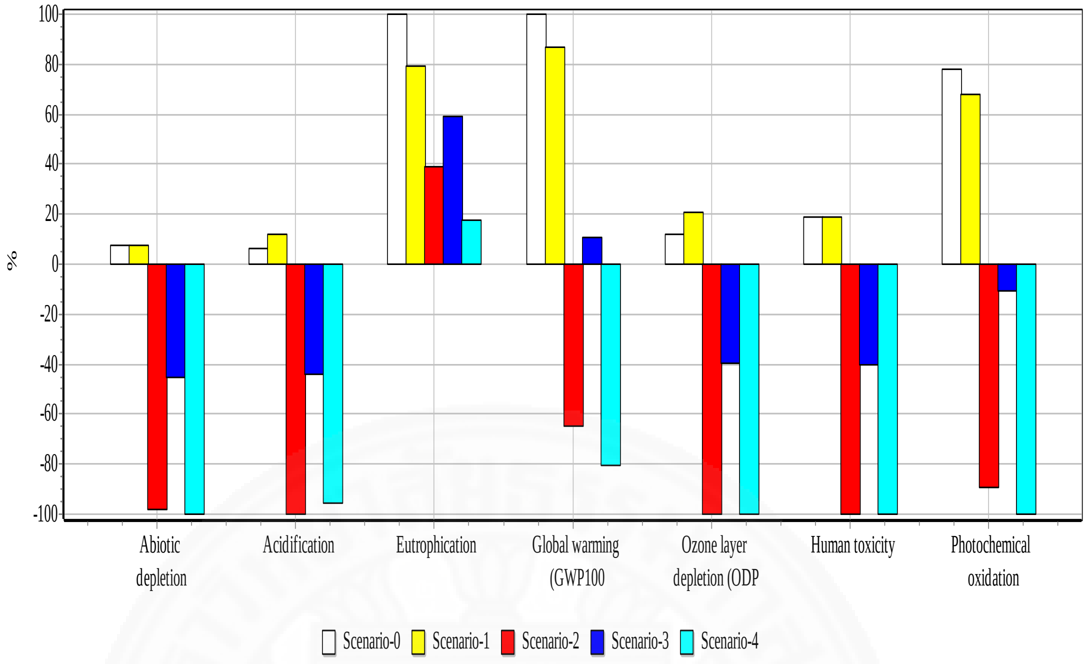
In this impact category, just provides smaller impact (-100%) in Scenario-4 due to composting and recycling large amount of solid waste. However, Scenario-0 is the most noticeably bad situations due to landfilling total solid waste generated in Paro district as shown Figure 4.12. Landfilling has highest emission due to methane gas emission.



Method: CML 2 baseline 2000 V2.05 / World, 1995 / Characterization
Comparing processes;

Figure 4.12 Photochemical Oxidation results for Scenario 0-4

Scenario-0 that is disposing of all mixed waste in the sanitary landfill without any treatment option is not an environmentally effective method. Global warming potential is to a great extent higher in 100% landfill than that for recycling. In Scenario-0 and Scenario-1, Abiotic depletion and Human toxicity contribution to the overall scoring is equal when compared to any other scenarios as shown in Figure 4.13. Scenario-2, Scenario-3, and Scenario-4 shown the positive environmental impact of Abiotic depletion, Acidification potential, Ozone layer depletion, Human toxicity and Photochemical oxidation potential. In contrast to other scenarios, Scenario-4 (recycling 50% of recyclable waste and composting 50% of compostable waste) has the lowest potential for Abiotic depletion, Global warming, Ozone layer depletion, Human toxicity, and Photochemical oxidation due to maximum reduction of solid waste in the landfill.



Method: CML 2 baseline 2000 V2.05 / World, 1995 / Characterization
Comparing processes;

Figure 4.13 Characterization graph of the comparative LCA model

From the impact category characterization result, one could get the (wrong) impression of having higher and lower impact when it is compared to normalization results. Whether the impact category is high can only be determined by comparing it with a reference (a normal value). Therefore, the life cycle impact assessment includes as a fourth element, namely the normalization of impact categories against each other.

4.6.3 Normalization of the environmental impact

World 1995 values were chosen as normalization factors for all environmental impact categories as the worldwide standardization factors as it is recommended for undefined regional assessment frameworks. Normalization of the magnitude of the classification indicator results related to the values of reference where the diverse effect possibilities and utilization of asset are communicated on a common scale through relating them to a common reference compares the environmental impact across the impact category of the alternative scenarios. The results of the normalization analysis per functional unit of 1 ton of solid waste generated from household and hotel sectors for each impact category for each scenario are shown in

Figure 4.14 and Table 4.16. The total environmental impact potential for 100% landfilling, composting 50% of food waste, recycling 50% of recyclable waste, recycling 25% of recyclable waste and composting 25% of food waste and recycling 50% of recyclable waste and composting 50% of food waste are 4.07E-11, 3.46E-11, -6.51E-11, -1.53E-11 and -7.13E-11 respectively.

Table 4.16 Normalization value for each impact category for each scenario

Impact category	**Scenario-0**	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
ADP	3.04E-12	2.42E-12	-3.16E-11	-1.46E-11	-3.22E-11
AP	1.01E-12	1.58E-12	-1.30E-11	-5.70E-12	-1.24E-11
EUP	1.93E-11	1.53E-11	7.47E-12	1.14E-11	3.39E-12
GWP	1.25E-11	1.06E-11	-7.92E-12	1.33E-12	-9.83E-12
ODP	1.08E-14	1.08E-14	-5.17E-14	-2.05E-14	-5.17E-14
HTP	3.49E-12	3.48E-12	-1.84E-11	-7.48E-12	-1.85E-11
PO	1.38E-12	1.18E-12	-1.55E-12	-1.81E-13	-1.74E-12
Total	4.07E-11	3.46E-11	-6.51E-11	-1.53E-11	-7.13E-11

Note: Negative values represent an advantage in environmental terms because impacts are avoided.

Normalization value also demonstrates that landfill situation has the highest environmental impact on Eutrophication and Global warming potential than the recycling and composting situation. The normalization per category analysis for each scenario also reveal that the Abiotic depletion potential is less compared to other impact categories.

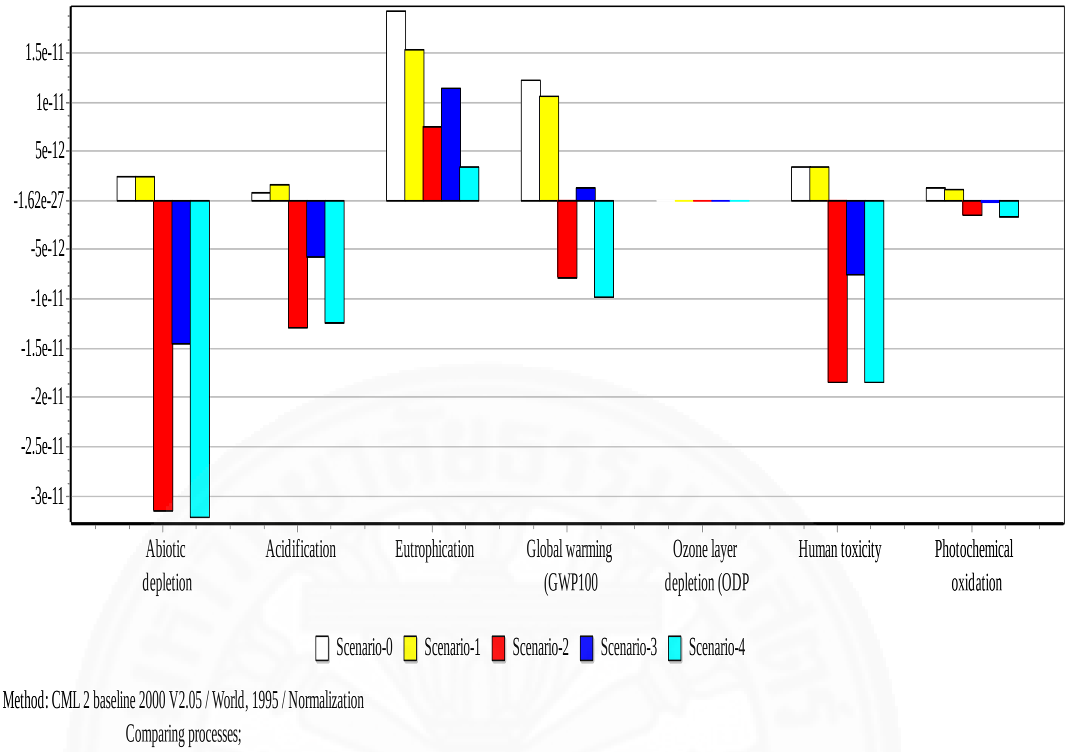


Figure 4.14 Normalization graph of the comparative LCA model

Figure 4.15 shows overall environmental impact in percentage for all scenarios. Scenario-4 followed by Scenario-2 shows a critical diminishment of environmental impact contrasting with the rest scenarios. This is mainly due to the majority of the waste generated in Paro is assumed to be sent to recycling and composting facilities. When comparing scenarios like Scenario-2 (25% of recyclable waste for recycling and 25% of food waste for composting) and Scenario-4 (50% of recyclable waste for recycling and 50% of food waste for composting), less percentage of waste materials treated in recycling and composting facilities in Scenario-2 led to increase the waste being disposed to landfill. Thus, more amounts of contaminants were released with contrast to Scenario-4. In this study, the use of recycling activity of recyclable wastes such as plastics, metal, paper, glass and other non-biodegradable materials shows an effective method for decreasing the landfill impacts.

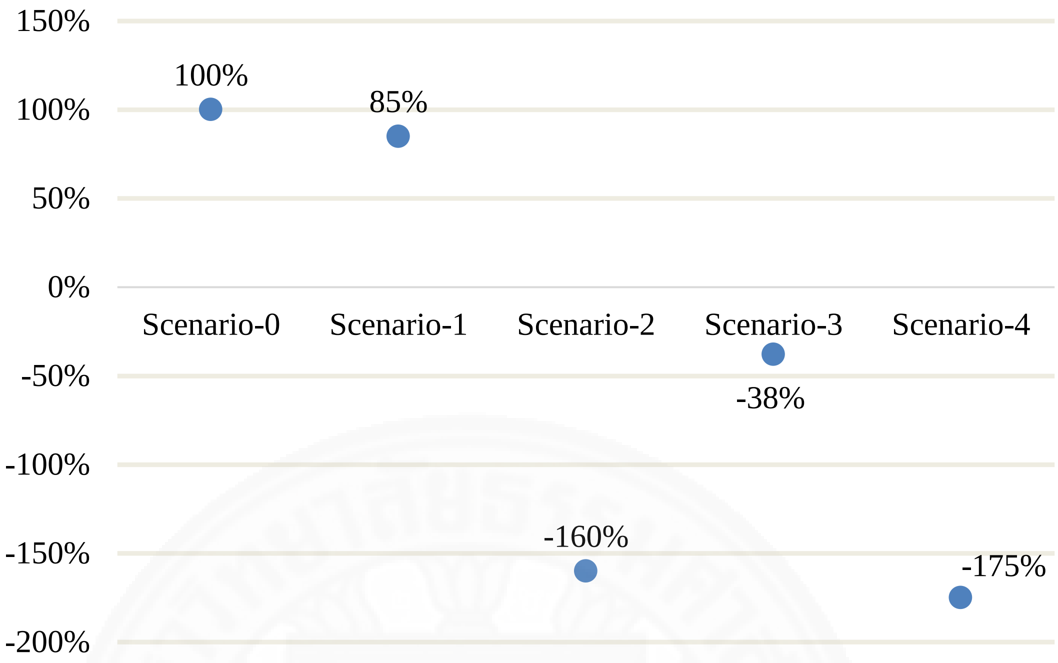


Figure 4.15 Overall environmental impact in percentage

- **Scenario-0**

In this scenario, landfilling is considered as the last stage of the waste management system without any other treatment and disposal technologies. The CML2 baseline approach rates 100% landfill as the most exceedingly terrible situations, this is principally owing to a considerably higher contribution to Global warming, and Eutrophication potential. Among seven impact categories, the lowest impact potential for Scenario-0 is the Ozone layer depletion potential and the highest contribution in terms of Eutrophication and Global warming potential due to landfilling food waste. However, this result is based on sanitary landfill instead of open landfill, the emission of pollutant could have been even higher for Scenario-0 in the real situation. The highest contribution could have obtained due to the absence of gas and leachate collection system in the real situation. Thus, it is the minimum favored option.

- **Scenario-1**

This appears to show that the present waste management isn't ideal whereby 100% of waste which are not treated are landfilled. However, overall environmental impact is reduced from 4.07E-11 (100%) to 3.46E-11 (85%) in this composting scenario of 50% food waste generated. Among seven impact categories, the lowest impact potential for Scenario-1 is the ozone layer depletion potential with 1.08E-14 and the highest contribution in terms of Eutrophication with 1.53E-11 due to composting 50% of food waste and the remaining 50% of food waste is disposed in the landfill. These processes of composting and landfilling of food waste cause Acidification potential due to emissions of SO_2, NO_x, N_2O and NH_3. The contributing effects that advantage from the impact reduction is Abiotic depletion potential to 2.42E-12 from 3.04E-12 in Scenario-0 due to reduction of air emissions from the landfill.

- **Scenario-2**

Recycling half of total recyclable waste is yet the better situation, having less environmental effect. For this 50% of recycling scenario, environmental impact is reduced further from 3.46E-11 (85%) to -6.51E-11 (-160%) due to addition of recycling station for recyclable waste materials. The contributing effects that advantage of the impact reduction is Global warming with -7.92E-12 and Eutrophication with 7.47E-12 in this scenario when it is compared to the previous scenario. Among seven impact categories, the lowest impact potential for Scenario-2 is the Abiotic depletion potential with -3.16E-11 and the highest contribution in terms of Eutrophication potential with 7.47E-12.

- **Scenario-3**

The general environmental impact for previous scenarios is decreased because of recycling, treatment scenarios of 50% recyclable waste. However, overall environmental impact is increased in this scenario from -6.51E-11 (-160%) to -1.53E -11 (38%). Similarly, the lowest impact potential for Scenario-3 is also from Abiotic depletion potential and the highest contribution is also from Eutrophication potential with among seven impact categories. However, Eutrophication potential has been increased from the previous scenario from 7.47E-12 to 1.14E-11 and Abiotic depletion from -3.16E-11 to -1.46E-11. The major contributing effects increment is Global warming in this scenario with 1.33E-12 from -7.92E-12 in Scenario-2. This is mainly because of landfilling 75% of food waste generated in the landfill, which led to air emission substances.

- **Scenario-4**

For this 50% of recyclable and compostable scenario, environmental impact is reduced from -1.53E-11 (-38%) to -7.13E-11 (-175%) due to the large reduction of solid waste in the landfill which reduces the air and water emissions from the previous scenarios. The contributing effects that benefit from the impact reduction is Global warming with -9.83E-12 and Eutrophication with 3.39E-12 in this scenario when it is compared to the previous scenario. Among seven impact categories, the lowest impact potential for Scenario-4 is the Abiotic depletion potential with -3.22E-11 and the highest contribution in terms of Eutrophication potential with 3.39E-12.

In summary, Scenario-4 is the best, however, to immediately jump from Scenario-0 to Scenario-4 may not be possible in the current situation. Small change from Scanario-0 to Scenario-3 and gradually shift toward Scenario-4 is likely in real situation. Additional actions such as development of cost effective techniques for waste recycling and associated management practices like installing waste containers and recycling facilities and public awareness through composting and recycling training and workshops with the end goal to understand the importance of separating waste at source may be needed to facilitate the shift.

In the perspective of the discourse above, the normalized values of worldwide normalization factors for functional unit of 1 ton of solid waste generated may show with small impact potential if it is compared with worldwide data. This is mainly because of less number of populations with the least amount of waste generated. However, if it is estimated on the yearly impact potential of the yearly generated municipal solid waste in Paro district, the impact will be higher than the current LCA results. MSW collected from Paro district and dumped in the landfill is 64.061 tons per day, which is equivalent to 23382.27 tons/year. Environmental impact potential from different waste management scenarios in terms of annual total solid waste generated in Paro district has the major impact as shown in Table 4.17.

Table 4.17 Normalization value of yearly impact potential for different scenarios

Impact category	Scenario-0	Scenario-1	Scenario-2	Scenario-3	Scenario-4
ADP	7.11E-8	5.66E-8	-7.39E-7	-3.41E-7	-7.53E-7
AP	2.36E-8	3.70E-8	-3.04E-7	-1.33E-7	-2.90E-7
EUP	4.51E-7	3.58E-7	1.75E-7	2.67E-7	-7.93E-8
GWP	2.92E-7	2.48E-7	-1.85E-7	3.11E-8	-2.30E-7
ODP	2.53E-10	2.53E-10	-1.21E-9	-4.79E-10	-1.21E-9
HTP	8.16E-8	8.14E-8	-4.30E-7	-1.75E-7	-4.33E-7
PO	3.23E-8	2.76E-8	-3.62E-8	-4.23E-9	-4.07E-8
Total	9.52E-7	8.09E-7	-15.20E-7	-3.56E-7	-18.27E-7

Note: Negative values represent an advantage in environmental terms because impacts are avoided.

Tremendous measure of MSW generated every year in Paro district is an environmental and health hazard if current waste treatment practices (open landfilling frameworks) keep on being executed. Moreover, because of the quick populace development and expanding measure of municipal solid waste generation impact in major pollution into air, water and soil, particularly in capital city of Bhutan compared with potential impact caused by Paro district per year. To decrease the volume of MSW that goes to the landfill, source lessening ought to be taken as the highest priority. Combining waste management scenario with sanitary landfill, recycling and composting would decrease the environmental impact of the process. Results from this LCA study can support huge parts in the improvement of future waste management approaches and support on decision making with respect to planning and optimizing sustainable solid waste management.

Chapter 5

Conclusions and Recommendations

This section concludes about the last finding of the study which likewise incorporate the recommendation for conceivable improvement of waste management in Paro district, Bhutan.

5.1 Conclusions

This investigation provide understanding on present practices of solid waste management in Paro and its impact on the environment as well as to the human health, which straightforwardly or in a roundabout way advances a sound scenario and enhances human wellbeing. The municipality in Paro district still facing with genuine difficulties radiating from the immense extension in urban advancements, the undeniably unsustainable way of life and utilization style. For the most part, Paro is having difficulties in establishment of proper waste management framework. The most astounding waste component is the organic waste that contributes half of the total amount of waste. Recycling and composting scenarios were most encouraging and reasonable approach to reduce the waste generated in Paro when it is contrasted with a present situation from the LCA result since it has a minimal environmental impact potential.

Out of various alternatives, Scenario-4 has the lowest environmental burden on the characterized affect classifications, from Abiotic depletion potential, Acidification potential, Eutrophication potential, Global warming potential, Ozone layer depletion potential, Photochemical oxidation and Human toxicity potentials indicators. In this way, training on solid waste separation at the source which isn't normally practiced in Paro is exceptionally important for composting and recycling system. Furthermore, executing the proper solid waste administration structure and selecting a feasible framework by the waste administration association will resolve the future issue of landfill in Paro district. Application of good decision in waste management programs and training to the hoteliers and the public is important through full support from incentives. To raise more attention to the general population of Bhutan on sustainable solid waste management, research on environmental burden caused by the current solid waste management system of quantified waste generation and composition is fundamental.

5.2 Recommendations

For viable solid waste management in Paro district, the basic factors as examined in chapter four ought to be satisfactorily tended to and enhancements ought to be made where appropriate. Majority of the challenges encountered are lack of awareness on waste management, inadequate waste separation at source, lack of recycling facilities, lack of regulations and insufficient funds. Some of the suggestion expressed underneath are drawn from best practices in other districts:

Education on waste- Educational programming will be more effective than policing - in changing the perspective on solid waste management issues in Paro district. With an end goal to increase recycling waste materials and enhance the life expansion of landfill through a thorough training program. This activity includes waste team providing awareness campaign through free waste management information and tools to the public, school and institution in Paro with the full support from teachers and volunteers.

The southern village called Pemathang in Samdrup Jongkhar district is one of the best example of waste education program in which most of the farmers are provided an awareness on how to minimize the waste by recycling PET bottles and plastics into the monetary system like bags, pencil bags, and baskets. Pemathang administrative officers trained farmers mostly woman and form a group called “Pemathang Zero Waste Committee” in which it has been successful in reduction of PET bottles and plastic waste. Furthermore, monasteries in this village have also agreed not to accept offerings packed in plastics to reduce plastic waste after this waste reduction program.

Waste reduction facility- Shedding machine is required in Paro like Thimphu district which has a capability for shredding PET materials of 32 kilograms' pellets per day to lessen the volume of PET bottles and minimize the transportation cost before trading in India. The quantity of PET bottles in Paro might not be higher than Thimphu and the best option will be transporting PET jugs to Thimphu for shredding into pellets as the distance between two districts is only 55km. Similarly, all sort of paper waste can reduce by transporting to Jemina paper recycling unit which is 22km distance far from Thimphu city. Such sort of routine with regards to recyclable waste would reduce waste-to-landfill and emission of greenhouse gas.

Some of the suggestion expressed underneath are for hotel industries:

1. Association of government by giving motivating forces to the hotel sector is required to receive ecofriendly well-disposed practices. Furthermore, the government needs to recognize and standardize the training by establishing rewards/prizes and providing tax benefits.
2. Administrators of tourism firms ought to have rules and inspiration to actualize environmental practices, for example, minimum resources utilization, obtaining only green item, and waste minimization exercises.
3. The nearby authority should bolster lodgings in composting training and benefit awareness to the staffs and even to the community. Composting practices in hotels are highly recommended to lessen the natural waste in the landfill and to decrease the ecological effect. The most critical factor is the waste separation quality at source for the successful fertilizing the soil result.
4. Extraordinary training ought to be produced for hoteliers to bring waste issues to light and instruct staff on the most capable strategy to reduce and reuse and furthermore, include clients in the lodging's waste recycling program. Example, reusing cardboard boxes for storage purposes, reusing remaining tissue rolls and cleansers from visitor spaces for inner utilize, refilling utilized cleanser bottles. Another technique for spreading mindfulness is by promoting hotel's environmental responsibility.

5. Develop monitoring systems and standards for each area of the hotel to set up green hotels. Monitoring of waste segregation at source should be taken as seriously important.
6. Concentrating on waste lessening in the landfill by establishing transfer station to separate recyclable and non-recyclable waste materials is necessary.
7. Assemble the functional connections among hotels, resorts, and responsible waste collection associations to lead great practices of solid waste administration. Getting diverse thoughts with multi-partners of various locale is important to propose the waste usage procedure like showed in Figure 5.1.

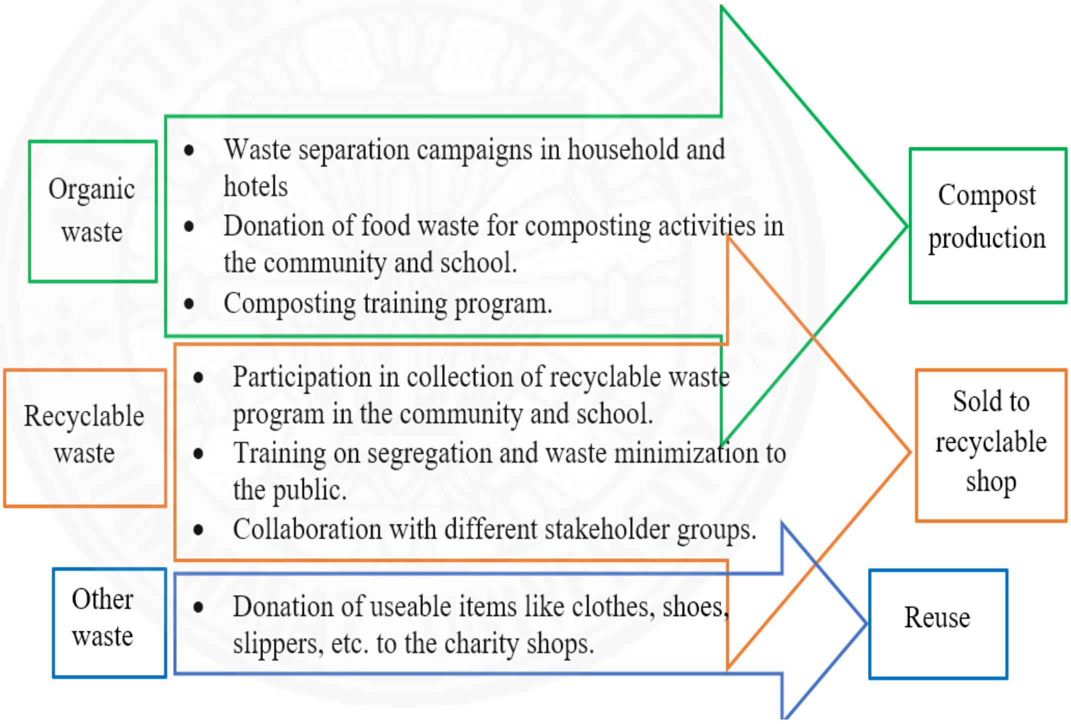


Figure 5.1 Proposed waste utilization strategy

5.3 Limitations of the study

Some of the limitations in this study are as follows:

1. Total number of occupancy in each hotel category was estimated that 70% of total rooms are occupied as it was confidential information to provide.

2. This LCA study utilizes ecoinvent database available in the SimaPro software for all the processes in developed scenarios to analyze the impact potential of various impact categories.
3. Instead of an open landfill (which is the current practices in Paro district), sanitary landfill module from the ecoinvent database was used to develop scenarios as there is no such thing as an "open dump/landfilling" module in ecoinvent.
4. Distances for transportation of solid waste for all the scenarios are same.

Therefore, keeping in mind the end goal to secure the real data, cooperation between the pertinent authorities is required. Most of the outcomes of this research are intensely subject to the assumptions of the plan of proper solid waste management framework through various scenarios. Additional future research can be coordinated at recognizing and portraying the effect on the consequences of the assumptions that have real significance for the principle outcome.

LCA study was done based on the waste fraction analysis which deals with waste management alternatives from an environmental point of view and it is also recommended to study on economic and social effects of solid waste management in the future study. Furthermore, CML2 baseline 2000 evaluation strategy demonstrates results with environmental impact potential and without any comprehension of the potential harm that might dispensed through them. Thusly, further investigation on environmental effect examination is exceedingly suggested for the future work using Eco-indicator 99 impact assessment method which is a damage oriented method for life cycle assessment.

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Appendices

Appendix A

Photos from field observation

1. Field observation in Paro district

- Current landfill site

- Scavengers collecting recyclable waste materials at the landfill site

- Municipal waste collection vehicles

- Druk waste collection vehicle

- Waste collection receptacles in hotels

- Waste composition in hotels