Lappeenranta University of Technology
School of Energy Systems
Degree Program in Energy Technology
Sustainable Technology and Business

Raj G C

WASTE TO ENERGY POSSIBILITIES AND GHG EMISSIONS FROM MUNICIPAL SOLID WASTE MANAGEMENT OPTIONS IN KATHMANDU METROPOLITAN CITY.

Examiner: Professor Mika Horttanainen
D.Sc. Tech Jouni Havukainen

ABSTRACT

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Waste to Energy Possibilities and GHG Emissions from Municipal Solid Waste Management Options in Kathmandu Metropolitan City.

Master's thesis

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Key Words: Municipal Solid Waste, Energy, Incineration, Refuse derived fuel, Waste management, Emission, Biogas, Landfill gas recovery, Anaerobic digestion.

The management of municipal solid waste (MSW) in Kathmandu metropolitan city (KMC) is a key issue and is at the increasing rate causing a severe effect on the environment and human health. The current waste management system in KMC is fixated on waste collection and disposal. With the identification of the existing problem, this thesis work aims at discovering various waste to energy (WtE) options, calculating greenhouse gases (GHGs) emission and providing a recommendation for the better optimization.

In this thesis work, the waste management options are divided into five different scenarios including the present scenario. In scenario 1 or baseline scenario the total amount of MSW collected is disposed of to the landfill site. Scenario 2 includes mass incineration of the total collected MSW. In scenario 3 the collected MSW fractions are disposed of to the landfill site, where methane gas is collected through landfill gas recovery option. In Scenario 4, the mixed MSW after source separation of an organic waste fraction is taken for Refuse-derived fuel (RDF) preparation in Mechanical biological treatment (MBT) plant. The organic rejects

from the process are landfilled, metal rejects are recycled, and RDF is incinerated. In Scenario 5 the separately collected organic waste fractions are anaerobically digested, metal and glass are recycled, and all other remaining waste fractions are landfilled.

The estimated net calorific value of MSW in KMC is about 4,07 MJ/kg which is technically not feasible for the mass incineration. To carry out the mass combustion process in scenario 2 the coal is added to the system to obtain the net calorific value of 7 MJ/kg. The highest electricity generation is from scenario 2 but the system is not fully renewable. The electricity generation from Scenario 3 is the best option as it is a fully renewable system which generates electricity of about 12 800 MWh annually. Moreover, the scenario 4 is also a good option with electricity generation capacity of 43 200 MWh where there is an addition of small amount of coal (i.e. 1 245 t/a) to the system. Compared to the present Scenario 1, the GHG emission reduction of about 64% or by about 82 000 t/a is viable in Scenario 3. The MSW fractions of KMC is highly organic, which is best suitable for electricity generation through landfill gas recovery option and AD process.

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Riihimäki

Raj G C

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LIST OF SYMBOLS AND ABBREVIATIONS

η_e	Electricity Generation Efficiency
AD	Anaerobic digestion
ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
APO	Asian Productivity Organization
CH_4	Methane
CO_2	Carbon Dioxide
DOC	Degradable Organic Carbon
EPA	Environmental Protection Act
F	Fraction of Methane Gas in Landfill
GHG	Green House Gases
GTZ	German Society for International Cooperation
HCRW	Health Care Risk Waste
HCW	Health Care Waste
IPCC	Intergovernmental Panel for Climate Change
ISWMS	Integrated Solid Waste Management System
KMC	Kathmandu Metropolitan City
LHV	Lower Heating Value
LSMC	Lalitpur Sub Metropolitan City
MCF	Methane Correction Factor
MOLD	Ministry of Local Development
MoPH	Ministry of Population and Health
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
N_2O	Nitrous Oxide
NRs	Nepalese Rupees
OECD	Organization for Economic Cooperation and Development
SWM	Solid Waste Management

SWMRMC	Solid Waste Management and Resource Mobilization Centre
SWMTSC	Solid Waste Management Technical Support Centre
TS	Total Organic Solid
UDM	Urban Development Ministry
UNEP	United Nations Environment Program
VS	Volatile Solid
WtE	Waste to Energy

1. INTRODUCTION

1.1. Research Background

Increasing population, urbanization, improved living standards and industrialization have caused a rapid increase in the amount of Municipal Solid Waste (MSW). According to the World Bank, the approximate global MSW generation is 1.3 billion tonnes/year, which is projected to double by 2025. (Worldbank.org, 2012)

Lack of landfilling space, negative health, and environmental impact caused, and environmental legislation has forced municipal authorities and governments for appropriate management of MSW. To reduce the negative environmental and human health impact such as; loss of biodiversity, land, air and water pollution and infectious disease, MSW is either recycled or converted to heat, power, compost, and fuels.

Proper management of MSW is a critical issue, especially for developing nations. The deficit of technological resources and economy have lead developing nations towards open landfilling. Open burning of household solid waste, disposing them to the riverside, dumping, and littering are very common practices. This improper MSW management and disposal habit lead to all kind of pollution: land, air, and water. Open burning and improper incinerating habit cause air pollution. Greenhouse gases are generated in the dumping sides from organic waste. Improper disposal of waste in the urban areas causes blocking of drainage and bad odours. Infectious diseases are communicated via insects to the human health.

The average and approximate per capita waste generation of South Asia is 0.45 kg/day which is projected to increase by 71% to 0.77 kg/day in 2025 (Worldbank.org, 2012). The projected increasing amount of MSW, increased living standards and urbanization clearly indicates the importance of Municipal Solid Waste Management (MSWM).

According to Asian Development Bank (ADB), the average and approximate MSW generation is 1435 tonnes/day in 58 municipalities of Nepal. The approximate per capita MSW generation is 0.32kg/day. The waste generation varies highly depending upon the economic expenditure of a family and climatic conditions. Uncontrolled urbanization, increased living standard, poor management of MSW and lack of technological resources have intensified the problem related to disposal and recovery. (Adb.org, 2013)

The existing problem of MSWM is of greater concern to municipal authorities. Discovering this problem of solid waste management, this thesis work aims to identify the situation of MSWM system in Kathmandu Metropolitan City (KMC), compare various waste to energy (WtE) options, estimate Green House Gases (GHGs) emission associated and recommend policies for proper management of MSW in KMC.

This master dissertation can be used as a reference in future research and project, and the outcome of this thesis work can be utilized by various stakeholders for decision making.

1.2. Research Questions and Objectives

This master thesis is based on the following research questions.

- What is the current situation of MSWM in KMC?
- What are the energy recovery possibilities and GHGs emission associated with MSW of KMC in terms of technology?
- What could be the optimal policies for better management of MSW in KMC?

Inspiring from the research questions, the main objective of this thesis work is to study the current situation of MSWM in KMC and furthermore, compare various WtE possibilities. Four different technologies; landfill gas recovery, refuse-derived fuel (RDF) incineration, mass incineration, and anaerobic digestion (AD) is compared creating various scenarios. Also, GHGs emission from various waste management option is estimated in this thesis work. This thesis work also aims to provide policy recommendation for effective waste management to municipal authorities and various stakeholders. The outcome of this thesis work can be a reference for decision makers.

2. BACKGROUND STUDY ON MSW GENERATION AND TREATMENT

2.1. Municipal Solid Waste (MSW)

Everyday waste generally recognized as garbage or trash generated by household, commercial or institutions is simply known as MSW. It is composed of everyday items such as; food waste, plastics, papers, clothing’s, furniture, electronic appliances, rubbers and many more consumer related products. The composition of MSW highly depends upon the standard of living and geographical location. The share of organic waste is highest in the low-income countries whereas the share of plastic, paper and inorganic waste is higher in high-income countries. East Asia Pacific constitute of highest share of organic waste (i.e. 62%) and OECD (Organisation for Economic Cooperation and Development) countries have the least share of organic waste (i.e. 27%) (Worldbank.org, 2012). The generation rate of MSW depends upon the degree of urbanization, industrialization, people’s living standard and economic development of a country.

The approximate global MSW generation is about 1.3 billion tonnes per year. The OECD countries account the highest amount of MSW generation of 44% while South Asia and Africa account for least waste generation of 5%. The average per capita waste generation is 1.2 kg/day in the world. (Worldbank.org, 2012)

These generated MSW can be a great alternative to fossil fuels if WtE programmes are well implemented. But at the same time, it can be a source of environmental degradation if the right waste management system is not applied. The three R’s (reduce, reuse and recycle) of waste management if implemented appropriately can reduce the environmental degradation.

2.2. Municipal Solid Waste Management (MSWM)

MSWM indicates to the process of reducing, collecting, transporting, treating and disposing solid waste in a controlled manner within a legal framework. Proper management of solid waste is an essential factor for keeping an environment clean and utilizing the waste in a decent manner. The waste management hierarchy includes prevention, reuse, recycling, recovery and disposal as depicted in figure 1. Directive 2008/98/EC on waste sets the five-step of waste management in European Union.

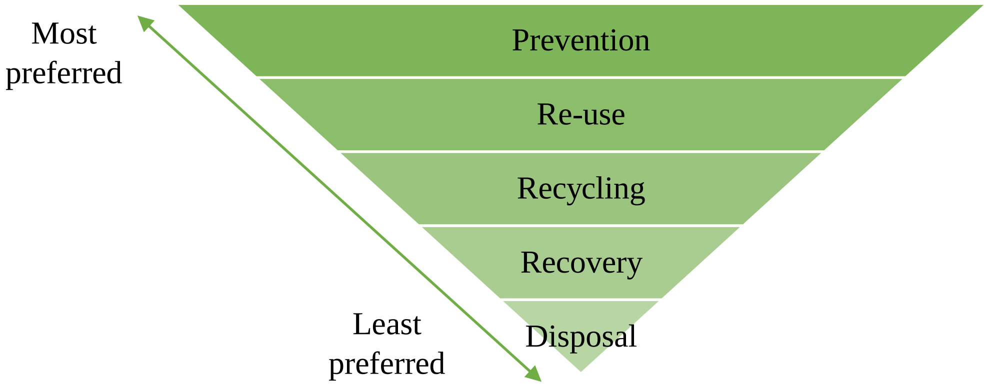

Figure 1: Waste management hierarchy (ISWA, n.d.).

Prevention: It is the most favoured approach of waste management which aims at not creating the waste or scale down the amount of waste. The amount of waste is reduced by avoiding unnecessary consumption of products and services. Decreasing the amount of materials during manufacture, less use of hazardous items and energy efficient production are some of the preventive measures.

Re-use: Use of the same product or part of the product in original motive for several times in one or another way reduces the amount of waste generation.

Recycle: The other approach to waste management is recycling. It includes the process of collecting recyclable waste and converting them into a raw material that can be used for a new product. Recyclable materials include those materials with high energy content and is cost-effective and less polluting. The recycling approach reduces the use of virgin materials in the market.

Energy recovery: Those materials which cannot be reused or recycled are taken to the energy recovery facilities. Energy recovery process converts waste into heat, power or fuels. This process helps in supporting energy demand and reduces the impact caused in the environment. The compost and ash from the material recovery processes upgrades the soil quality and supports constructive work. The different process of energy recovery includes: incineration, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery.

Disposal: It is the last option in the waste management hierarchy. Those waste which is not used for energy recovery or waste after energy recovery are disposed of in a designated area. The disposal is done within a limitation of a legal framework.

2.3. Waste to Energy Conversion

Waste to energy is the modern technique of converting waste into useful energy. It is a form of recovery. WtE is a widely used method as there is scarcity of landfills and huge impacts caused by MSW if disposed of without recovery. There are two major pathways for WtE conversion. They are thermochemical conversion and biochemical conversion. Waste with lower moisture content is best suitable for thermochemical conversion while the waste with higher moisture content is suitable for biochemical conversion. (Zafar, 2016). Figure 2 below depicts the WtE conversion pathways.

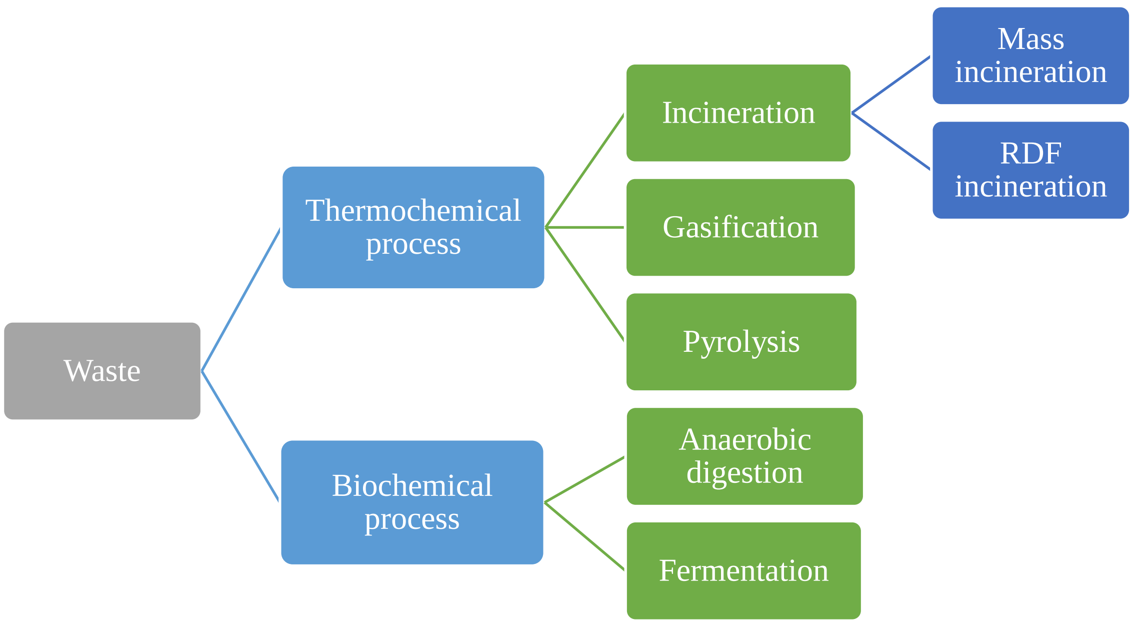

Figure 2: Waste to energy pathways (Zafar, 2016).

2.3.1 Thermochemical Conversion

The thermochemical conversion process of waste fraction takes place either in excess air, i.e. combustion, gasification in the reduced air or pyrolysis in the absence of air. The process decreases the size, volume and toxic substances of waste inputs and recovers the energy content.

Incineration: Incineration is the most widely used WtE technique. This system has evolved dramatically with new system designs. Despite being the most abundant method of solid waste management after landfilling, it produces residues and harmful substances that cause air pollution.

A schematic diagram of an incinerator facility is displayed in figure 3 below. It consists of several process sections such as; waste receiving and storing unit, feeding system, combustion unit, boiler area, air pollution control unit and ash handling section. The major portion of residue is produced in the combustion unit. Wastewater is emitted in waste storage and ash quenching area.

The investment cost of incineration facility is high, and the payback period varies a lot in different countries. They are designed for a certain calorific value of a waste stream and residues produced during incineration requires proper disposal.

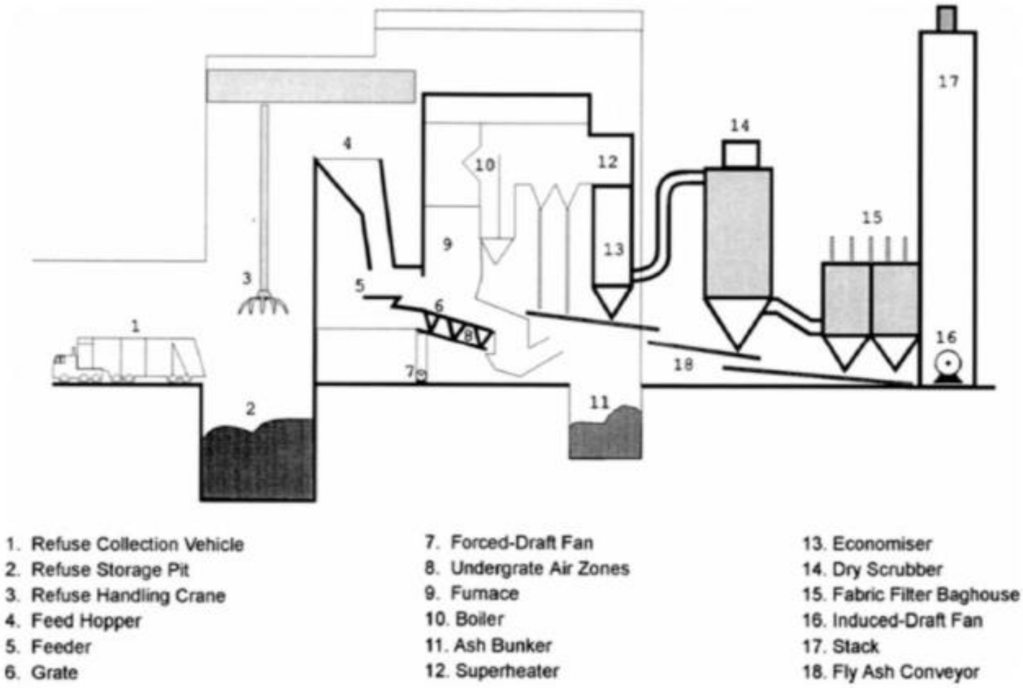

Figure 3: Schematic diagram of an incinerator plant (Chandler et.al, 1997).

Incineration of MSW can be either mass burning or RDF burning. In mass burning the received waste is feed into the furnace as it is received. No pre-treatment is carried out during mass incineration. In RDF burning homogeneous nature of waste is prepared before feeding it to the furnace. The MSW is shredded into a smaller size and non-combustible waste are separated by mechanical separation. However due to incomplete mechanical separation there remains some amount of non-combustible waste fraction and some amount of combustible waste fractions are also separated. Preparation of RDF helps to increase the calorific value of the waste streams, facilities transportation, low pollutant emission and easier storing than the original waste (Chandler et.al, 1997). However, the capital cost for incinerating per ton of RDF is higher than that of mass incineration.

Gasification

In the gasification process the waste is not combusted directly instead, it is a process where carbon-containing materials are transformed to useful synthetic gas or syngas. This syngas can be further used for power generation or for production of chemicals, fertilizers and transportation fuels. During the gasification process, the MSW or carbon-containing waste is feed to the gasifier where chemical reaction occurs in low oxygen availability. High temperature caused by partial combustion breaks down volatile solids and converts them into gas. The simple gasification process is depicted in figure 4.

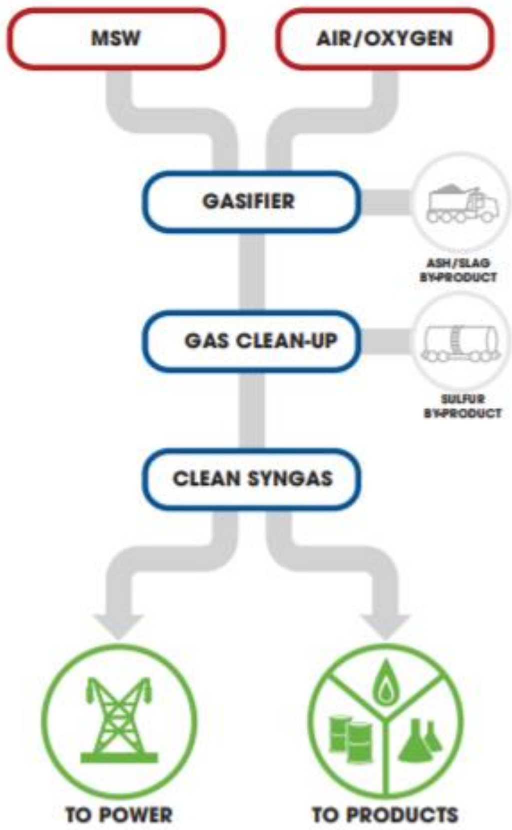

Figure 4: MSW gasification process (Gasification-syngas.org, n.d.).

Gasification process enhances the recycling process as it is necessary to remove inorganic substances such as; metal and glasses before feeding it to the gasifier. One ton of MSW produces up to 1000 kWh of electricity in gasification process. (Gasification-syngas.org, n.d.)

Pyrolysis

Pyrolysis is a thermochemical conversion of the organic waste stream into useful solid, liquid and gases in absence of oxygen. Compared to the combustion process pyrolysis requires lower external temperature and emits lower emission. The organic waste stream is heated externally under pressure or in the ambient pressure with a typical temperature above

430°C. Pyrolysis is gaining its popularity as it produces the combination of solid, liquid and gas and the proportion can be controlled with the variation of heating rate and temperature. (Czajczynska et.al, 2017).

2.3.2 Biochemical Conversion

Anaerobic digestion (AD)

In AD process the organic materials are breakdown with the help of microorganism in the absence of air. It is a biochemical process. The end-product is biogas and residue digestate which is used for generation of heat, power, biomethane, transportation fuels and as a fertilizer in the soil. Animal manure, food waste, yard trimming, fats, oils, greases, sewage sludge and industrial organic waste are generally fed to the digester. The basic process of producing biogas is illustrated in figure 5.

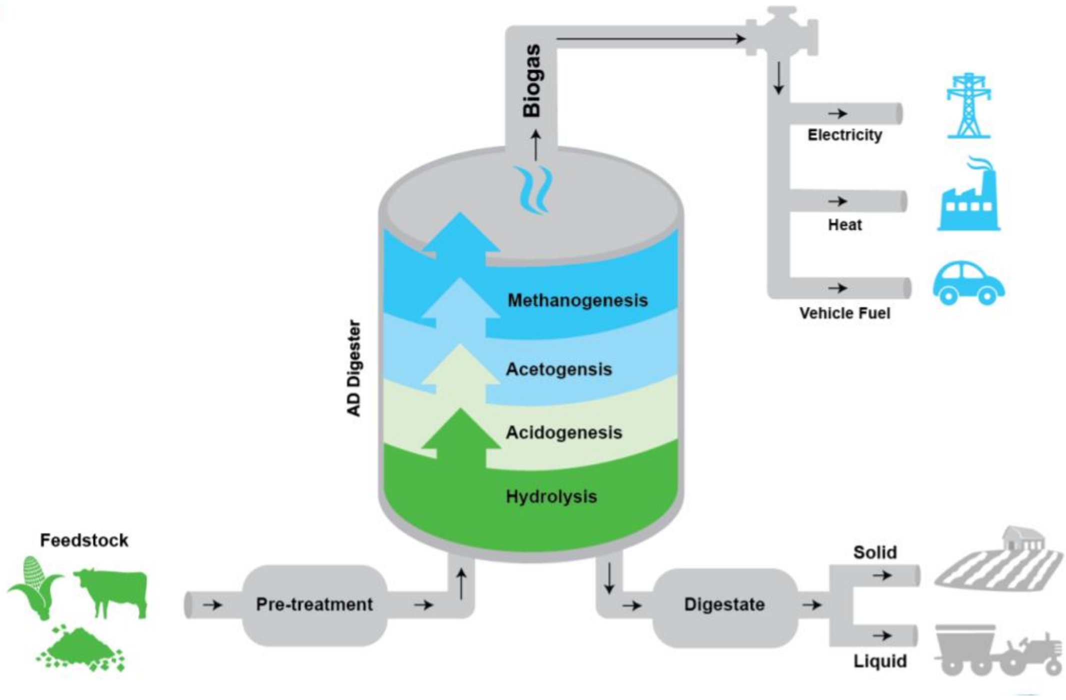

Figure 5: Biogas production from AD (Globalmethane.org, 2016).

Biogas contains mixture of methane, carbon dioxide, a small amount of water vapour and other gases which can be combusted for generation of heat and power. Methane is extracted from the biogas to produce so called biomethane and is supplied to the natural gas network as a renewable gas or used as a vehicle fuel. The coproduct of AD process is rich in nutrients and is used as a soil fertilizer. Careful selection of feeding material is necessary as contaminants can cause damage to AD equipment's. Waste such as; glass, metals, plastics, wood waste, soil, disinfectant, pesticides and other inorganic waste must be avoided from feeding to the digester. (Globalmethane.org, 2016).

Fermentation

Fermentation is the biochemical conversion of an organic waste stream where end-product is acid or alcohol. Such product includes ethanol, lactic acid, and hydrogen. Production of bio-ethanol from fermentation process which is a clean transport fuel has a great importance. The process is like that of anaerobic digestion, however the end-product in fermentation process is ethanol. The final step process in fermentation is a distillation and the end-product are alcohol or acid whereas in AD process the final step process in methanogenesis and output product is biogas. An AD process for MSW is practiced in large scale worldwide while few fermentation processes for MSW exist worldwide (Worldenergy.org, 2016).

2.4 Overview of MSW Generation and Disposal in South Asia

The South Asia comprises of 8 countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka) which produces about 70 million tonnes of waste per year. The average per capita waste generation is 0.45 kg/day. The highest amount of waste is generated in India followed by Pakistan. Those waste generated are typically transferred to landfills without any recovery.

Rapid urbanization is the key reason to increase the amount of MSW generation in South Asia. 29% of the region's population lives in the urban area. The urban population growth rate of this region is 2.6% per year. In India, 90% of the MSW is disposed of to the open dumping and in Bangladesh, only about 20% of the houses have access to MSW collection facilities. (Adb.org, 2013)

The rate of MSW collection is low in this region where most of the waste is burned or dumped in an uncontrolled manner. The uncollected wastes in the street and drains are the reason for water pollution and bad odour. The system of recycling is practiced in most of the South Asian countries both formally and informally. The collection of recyclables materials from dumping areas, collection points, and landfill sites are made by informal waste pickers. While the system of energy recovery or waste to energy plants are rare in this region.

3. MSW GENERATION AND MANAGEMENT IN NEPAL

Nepal is a landlocked country officially called as Federal Democratic Republic of Nepal. It is bordered with China in north and with India in East, West and South. The population of Nepal according to the census of 2011 was about 26 500 000. Nepal is also called as a country of Himalaya. The eight highest mountains out of ten in the world is located here, including the Mount Everest. Nepal being geographically beautiful the main industry in Nepal is tourism. In addition to that there are garment, food and beverages, herbs and many other factories. The net import of Nepal is very high compared to that of export. The per capita GDP of Nepal for the fiscal year 2016/2017 is 853 US$. (Cbs.gov.np, 2016).

3.1 MSW Generation and Composition

Generation

The MSW generation and composition of Nepal highly varies upon the geographical location and climatic condition. Nepal is geographically divided into 3 regions. They are; Mountain, Hilly, and Terai (Plane) region. The altitude of the country varies from 60m in Terai to 8848m in Mountain within a short range of 90-120 km (Pokhrel and Viraraghavan, 2005). The temperature between mountain and terai region varies from -25 °C to 40 °C. According to the survey carried out by Asian Development Bank (ADB) in 2011-2012 (Adb.org,2013), the average household daily waste generation of Terai region was 0.88 kg/households, 0.72 kg/households for Hilly region and 0.49 kg/households for Mountain region. The amount of MSW generation also depends upon the average monthly expenditure of a family. The average household waste generation based on monthly expenditure is depicted in figure 6. It clearly indicates that higher the expenditure, higher is the consumption rate and higher is the waste generation.

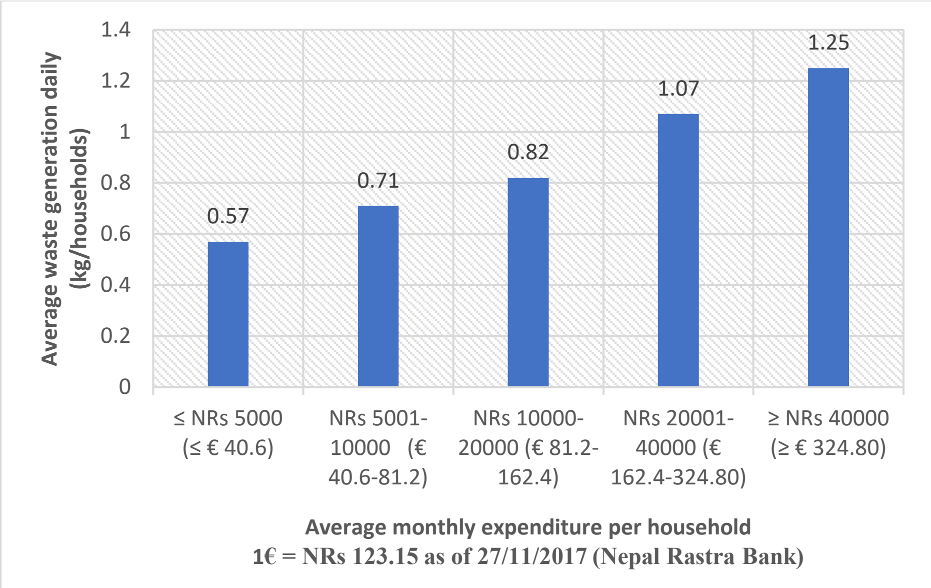

Figure 6: Average households waste generation daily (Adb.org, 2013)

The waste generation in Nepal is less compared to other countries and most of the waste comprises of non-hazardous and recyclable waste (UNEP, 2001). The waste can be a resource if managed properly. The main source of MSW in Nepal is household waste that varies according to the living standard of a family. The estimated average per capita MSW generation of a municipality based on the size of the population varies from 0.25 kg/person/day to 0.50/kg/person/day (Table 1).

Table 1: Average per capita waste generation based on population size (UNEP, 2001)

Municipality by population size	Waste generation (kg/person/day)
≤ 20,000	0.25
20,001-50,000	0.30
50,001-100,000	0.35
100,001-400,000	0.40
≤ 400,000	0.50

In 1997 the total waste generation by 58 municipalities of Nepal was 835.2 tonnes/day or 304 000 tonnes/year, which comprises of 83% of MSW, 11% of agricultural waste and 6% of industrial waste. The total population residing in these 58 municipalities was about 3 172 000 which is about 15% of the total population at that time (UNEP, 2001). According to the survey of JICA (Japan international cooperation agency) in 2004, the total MSW generation was 1370 tonnes/day or 500 000 tonnes/year by municipalities of Nepal. The survey conducted by ADB in 2011-2012 reported the MSW generation of 1435 tonnes/day or 524 000 tonnes/year from 58 municipalities. There is not much difference in the MSW generation in 2004 and in 2011-2012. The lower estimation by ADB may be due to the type of household selected during the survey. It can be also due to the type of survey carried out either questioner or site sampling. Also, the location of site sampling plays a key role in estimating the generation. The site sampling at core urban regions shows higher estimation while sampling in rural areas estimates the lower generation. The MSW generation and composition were estimated based on the site sampling in 3 233 households, 627 institutions (office and schools) and 627 commercial institutions (shops, hotels and restaurants) by ADB. In addition to that the survey include the thorough interview with municipal authorities responsible of MSWM. The total MSW generation per day in the municipalities of Nepal in different year based on the survey of different agencies is depicted in figure 7.

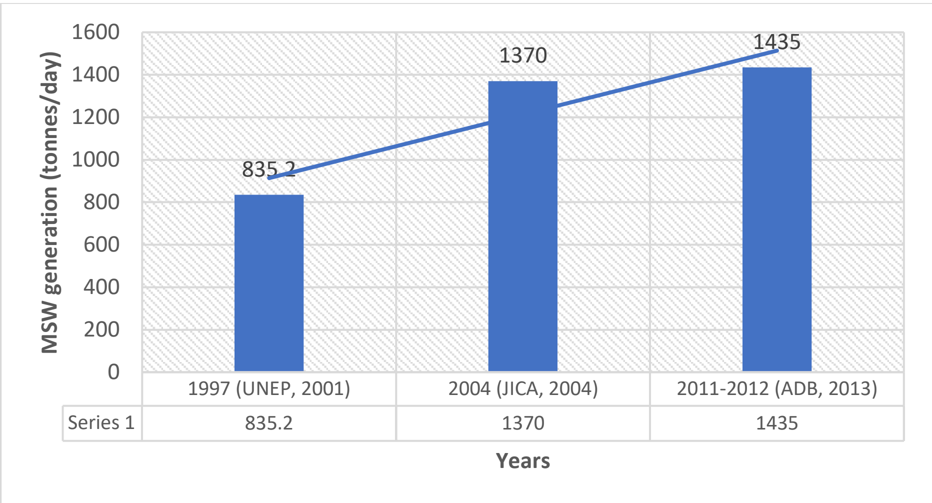

Figure 7: MSW generation in 58 municipalities of Nepal.

Nepal comprises of 58 municipalities until 2014. There are 217 total municipalities currently of which 72 were formed in May 2014, 61 were formed in December 2014, and other 26 in September 2015. According to the survey carried out in 2016 for 60 new municipalities, the MSW generation was about 419 tonnes/day or about 152,000 tonnes/year. The average per capita MSW generation was estimated about 180 grams per day. The value is low compared to the survey carried out by ADB for 58 municipalities. It is due to dominant rural areas, less population and less economic and commercial activities in those municipalities (Pathak, 2017).

Composition

The MSW constitute of household, commercial, and institutional waste in addition with agricultural waste, waste in street, waste from yards and waste produced by plants and animals. The composition and characteristics of MSW depend upon the ecological region, living habits, consumption patterns, climatic condition, culture and economic status. The composition of household waste, institutional waste, commercial waste and overall MSW for 58 municipalities of Nepal in 2011-2012 is depicted in figure 8.

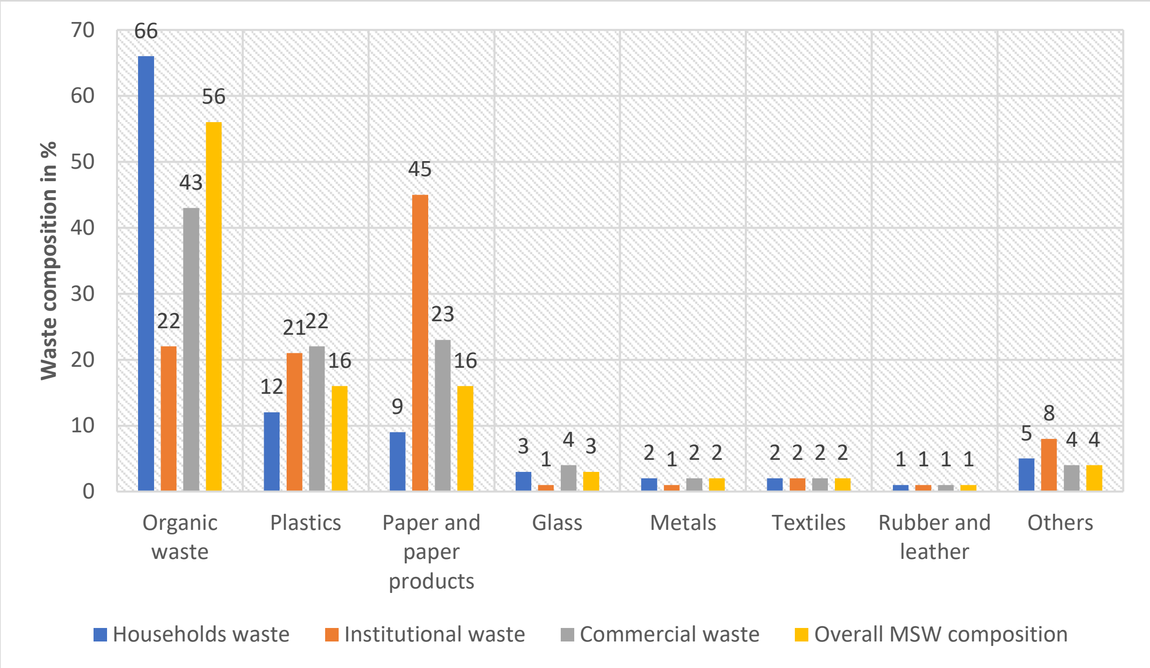

Figure 8: MSW composition in 58 municipalities of Nepal (Adb.org, 2013)

The share of organic waste is higher in household waste and lowest in institutional waste. This indicates that there is a good prospect of organic waste recovery. Paper waste is dominantly produced in the institutional sector rather than in household. Other wastes such as; plastics, glass, metals, textiles, rubber, and others are produced roughly equal. The overall MSW composition consists of 56% organic waste, 16% plastics, 16% paper, 3% glass, 2% textiles, 2% metals, 1% rubber and leather and 4% others.

The composition of MSW of 60 new municipalities based on the survey carried out in 2016 by Solid waste management technical support centre (SWMTSC) is illustrated in figure 9.

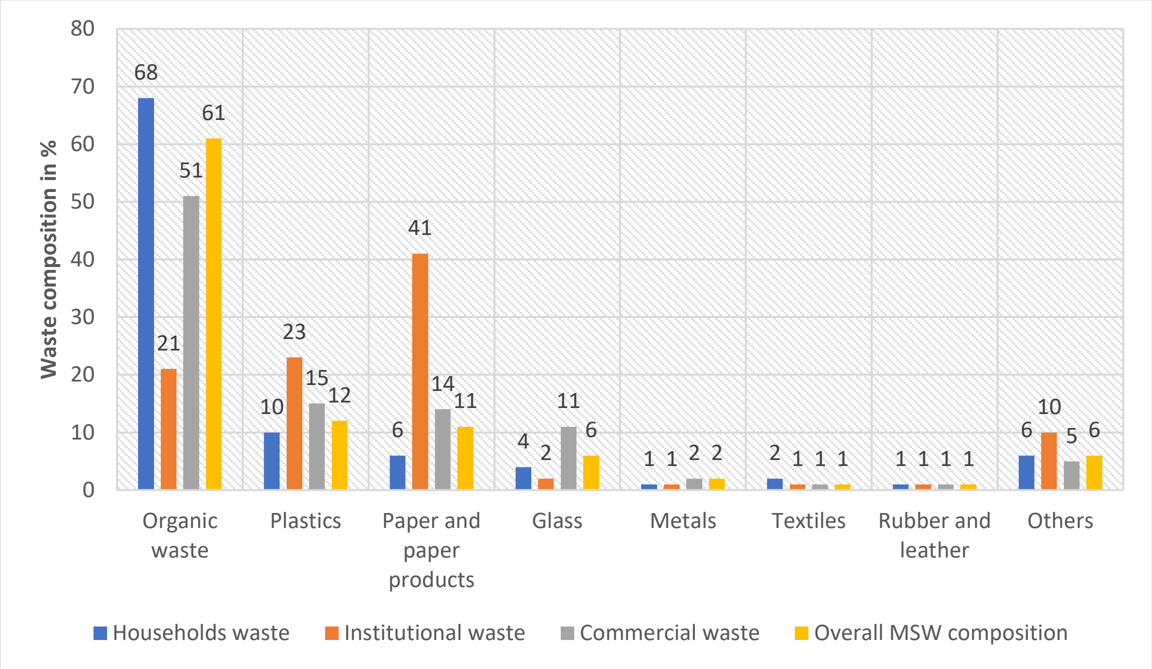

Figure 9: MSW composition of 60 new municipalities (Pathak, 2017).

The pattern of a waste composition of 60 new municipalities is like that of 58 municipalities. The overall MSW composition consists of 61% organic waste, 12% plastics, 11% paper, 6% glass, 2% metals, 1% textiles, 1% rubber and leather and 6% others.

The composition of commercial, households and institutional waste from 58 municipalities and 60 new municipalities is summarized in Appendix 1-6.

Moreover, the composition of MSW differs according to the geographical location. The organic waste is highly available in Terai region compared to that of Mountain region. Other waste fractions such as; plastics, papers, metal, glass, textile, rubber, and others are available roughly equal (Adb.org, 2013).

3.2 Waste Legislation, Rules and Policy

To improve the waste management system and to keep the environment clean and healthy government of Nepal has established various rules and legislation throughout the period. The major legislations for solid waste management (SWM) is represented in figure 10 in chronological order.

Figure 10: SWM legislations in Nepal.

3.2.1 Solid Waste (Management and Resource Mobilization) Act, 1987

The act directs the establishment of Solid Waste Management and Resource Mobilization Centre (SWMRMC) which was responsible for all kind of solid waste collection, storage, recovery, and disposal. The SWMRMC was responsible for controlling the impact of solid waste in the environment. SWMRMC could coordinate with other institution to control the waste production and disposal and it could also publicize the importance of SWM. The act came into effect in the Kathmandu, Bhaktapur and Lalitpur municipality immediately and will come into effect in other municipalities as prescribed by the government. The SWMRMC was responsible for organizing all kinds of activities and operating the functions related to SWM (Lawcommision.gov.np, n.d.). The act was the early legislation linked to the solid waste management in Nepal. However, the act is not functional today as SWMRMC is not involved in the waste management of Kathmandu (Apo-tokyo.org, 2007).

3.2.2 Solid Waste Management National Policy, 1996

Solid waste management national policy was enforced by the government as there was lack of proper SWM system in the country. The policy aims at managing solid waste at a simple and effective level, minimize the environmental and human health impact caused by solid waste, use solid waste as a resource, increase public awareness and privatize the solid waste management works. The national policy contains four major strategies for proper SWM. They are; public participation, technology, source mobilization, and privatization. The policy encouraged for SWM at the local level and manage solid waste according to their volume and nature (Swmtsc.gov.np,1996).

3.2.3 Environment Protection Act (EPA) 1997

EPA created in 1997 has the following provisions with respect to the SWM;

1. No institution or individual shall pollute the environment in any manner which causes the significant adverse effect on people's health and surroundings. Nobody shall produce sounds, radioactive rays, and wastes from mechanical devices or institutions above the prescribed standards.
2. If there appear such activities of significant effect on the environment and human's health, then Ministry shall prohibit carrying out such activities.
3. The use of fuels, substances or devices which causes an effect in the environment shall be forbidden if found above the standard level.

3.2.4 Local Self Governance Act, 1999

The act was formulated with an aim of decentralization. The ward committees under Village Development Committees (VDCs) were responsible for management of all kind of waste and keep the environment clean and healthy. The ward committees must protect the local environment, encourage local people towards sanitation and arrange collection, transfer, and disposal of solid waste within their territory (Pathak, 2017).

3.2.5 Solid Waste Management Act, 2011

The act stipulates 3R's (reduce, reuse and recycle) of waste management by systematic and effective processing to keep the environment clean and healthy and reducing the effect on human health. The local body is responsible for SWM by construction and operation of infrastructure such as; collection centres, transfer stations, processing plants, recovery plants, and disposal sites. It is the responsibility of local body to manage any kind of waste deposited in the collection centre. Here, local bodies represent municipality, sub-municipality, and VDCs. Medical institutions and industries are responsible to manage their biomedical and hazardous waste themselves. Local bodies shall manage their waste with charge if requested. No individual or private organization shall involve in the waste management without obtaining a license from local body. The local body shall provide license to the interested parties based on competition. The local body can collaborate with a private organization for SWM and charge fees to the public for collection, transfer, recovery, and disposal of solid waste. The act came into force from 15th June 2011. A survey showed that only 47 municipalities out of 58 municipalities have acquainted with the act but without the effective implementation (Pathak, 2017). Solid Waste (Management and Resource Mobilization) Act, 1987 was replaced by this act (Lawcommision.gov.np, n.d.).

3.3 Overview of MSWM in Nepal

Collection of waste on the street sides, riverbanks, open spaces, forest areas and temporary disposal areas are very common practices in Nepal. Open burning and traditional way of composting are common in the rural areas. However, the collection and disposal practices from different municipalities are made in various frequencies. The various mode of existing waste management system in Nepal is outlined below.

3.3.1 Collection and Segregation

The exact amount of waste collected and segregated in different municipalities cannot be known due to lack of scientific recording systems. Moreover, the study from ADB in 58 municipalities of Nepal discovered that 30% of surveyed household practices the source separation of different waste fractions (Adb.org,2013). The organic waste fraction is usually separated from other waste fractions. The higher rate of segregation is in the rural municipalities as they use their kitchen waste to feed the cattle and to prepare traditional compost. The efficiency of waste collection varies a lot among the municipalities. The door to door waste collection, container service and roadside pickup from a container or open pile are the waste collection practices in the municipalities of Nepal. Roadside pickup is the dominant practice among all practices.

The survey from Solid Waste Management Technical Support Centre (SWMTSC) in 60 new municipalities of Nepal found that 51% of household wastes are segregated (Pathak, 2017). The rate of segregation is higher in the survey of SWMTSC than that of survey of ADB because the 60 new municipalities are in the rural areas of the country, where they practice traditional compositing. The solid waste collection system in many municipalities are not existing, if existed they are not satisfactory. The waste from households are generally composted, open burned, buried and thrown in the riverbanks, streets or open temporary disposal areas.

3.3.2 Waste Transportation and Disposal

The waste generated in municipalities of Nepal is transported either by rickshaws, tractor or dump trucks. The availability of these vehicles and equipment's widely varies among the municipalities. However, most municipalities have one or the other vehicle. Only three municipalities; KMC, Lalitpur and Madhyapur Thimi have the transfer station. Transfer station (Teku transfer station) is used for collection of waste and no recovery options are executed here. All the waste collected by municipalities are openly dumped without any recovery. The various types of disposal practices from 58 older municipalities and 60 new added municipalities are illustrated in figure 11 and 12 respectively.

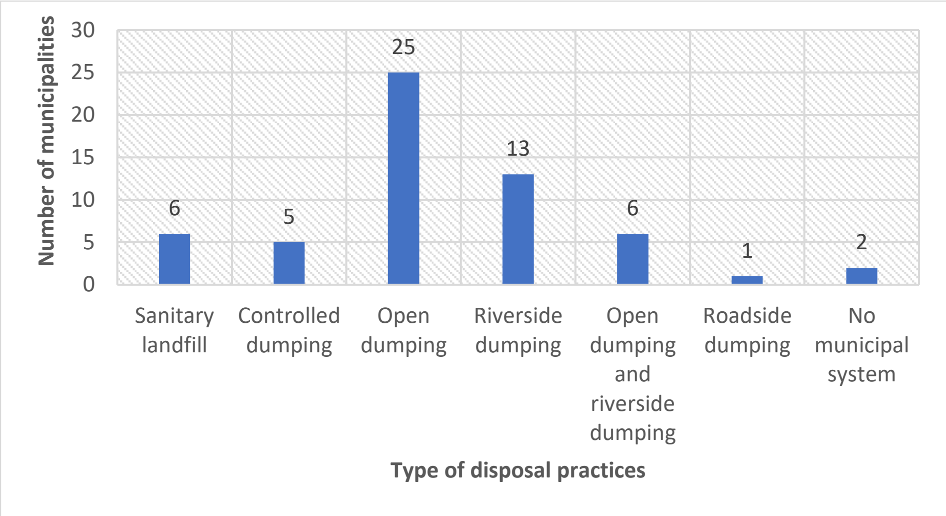

Figure 11: Municipal waste disposal method in 58 municipalities (Adb.org,2013).

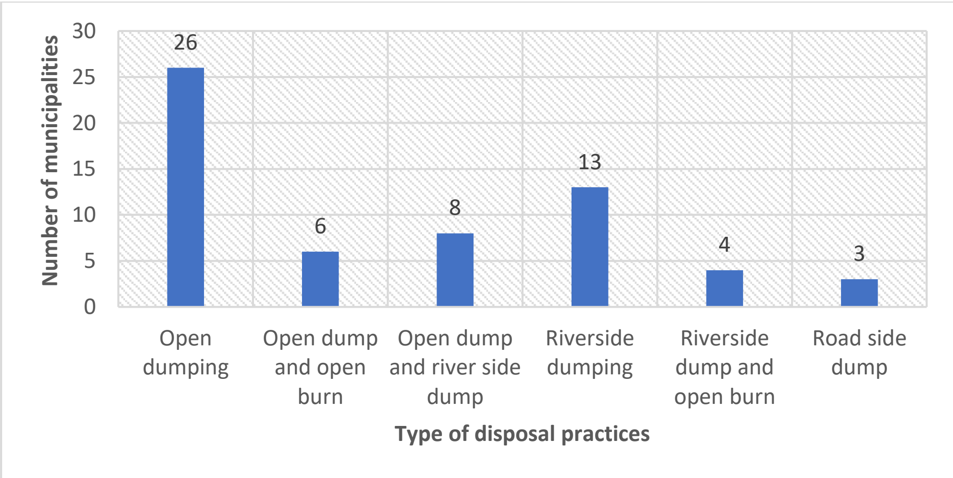

Figure 12: Municipal waste disposal method in 60 new municipalities (Pathak, 2017).

Open dumping is the most common form of waste disposal practiced by the most municipalities, creating the environmental and health problems. Out of surveyed 118 municipalities, 51 municipalities dispose of their waste in open space. Riverside dumping is also practiced by many municipalities. Only 6 municipalities have the constructed sanitary landfill sites, which are improperly managed due to lack of equipment's, local protests and inefficient management system.

Moreover, the most municipalities have plans to construct sanitary landfill sites, but the plans are not executed because of government's late decision, lack of technical and economic support, local protests and delay on approval of land acquisitions.

3.3.3 Resource Recovery Methods

Despite the SWM Act, 2011 emphasizes on reduce, reuse and recycle there are no formal resource recovery works existing in any municipalities of Nepal. It is due to lack of sufficient funds and technical resource in the municipalities. However, the 3R's of waste management reduce, reuse and recycle have been practiced at a household level and by small private organizations and NGO's. The recyclable waste such as metal scrap, bottles, plastics, and paper are collected and transported to India for further processing.

The recyclable household, commercial and institutional waste are collected and sold to the nearby informal waste collectors. Some informal waste collector can even be seen in the landfill sites and they are also available collecting waste door to door. It is estimated that there are 800 scrap shops collecting recyclable waste only in Kathmandu Valley (KMC, LSMC, Bhaktapur, Thimi and Kritipur municipality). The survey carried out by SWMTSC in Kathmandu Valley in 2013 on 120 scrap shops estimates that about 115 tonnes/day of paper, plastics, and metals are collected for recycling. In addition, 20 000 aluminium cans and 650 000 glass bottles are collected per day from MSW of Kathmandu Valley (Pathak, 2013).

Compositing is the other way of recovering organic waste. The waste composition of the MSW stream in Nepal is highly organic. The traditional way of composting is practiced in the households of rural areas. However, the urban households rarely practice such system. The survey from ADB in 58 municipalities and SWMTSC in 60 new municipalities noted that 30% of the household's practices composting.

There are no formal composting facilities operated by any municipalities, but there are few private companies preparing compost from organic waste. BioComp Nepal is one of the examples, which collects about 20-50 tonnes organic waste in a day within Kathmandu and prepares compost.

There is no WtE plant in operation in Nepal. In 2016, the KMC start a pilot project to generate biogas and electricity from it. The 14-kW electricity generation pilot project is under test for a year which will be replicated to other municipalities if found successful.

Although there is no commercial WtE plant in operation, it is assumed that there is about 35000 unit of biogas plant constructed in the households of Nepal (Araldsen, 2016). But the data provided by AEPC (Alternative Energy Promotion Centre) is a contrary which shows there are about 690000 biogas plants in Nepal constructed from the fiscal year 1992/93-2015/16 (Aepc.gov.np, n.d.). The data assumed by Araldsen was based on paper review with limited information because of which there is big difference on the data of biogas plants. The size of biogas plant varies from 4 m^3 to 10 m^3 and is used for cooking purpose in households (Subedi, 2015). The residue from biogas plant is used as a soil fertilizer. Those biogas plant especially uses animal manure as an input. The construction was successful since the biogas support program was started in 1992 with the support of the Netherlands, Directorate-General for International Cooperation. It is also forecasted that every year there will be 20,000 new units of biogas plant constructed in the household of Nepal. It is because the households in rural areas mostly have animals at their homes. The year wise installation of the biogas plant in Nepal from 1992/93 to 2015/16 is depicted in figure 13. There is a gradual increase in the installation of the biogas plant in Nepal which has a significant down fall in the year 2012/13. The average biogas plant installation in households of Nepal every year is about 25 000 (Aepc.gov.np, n.d.).

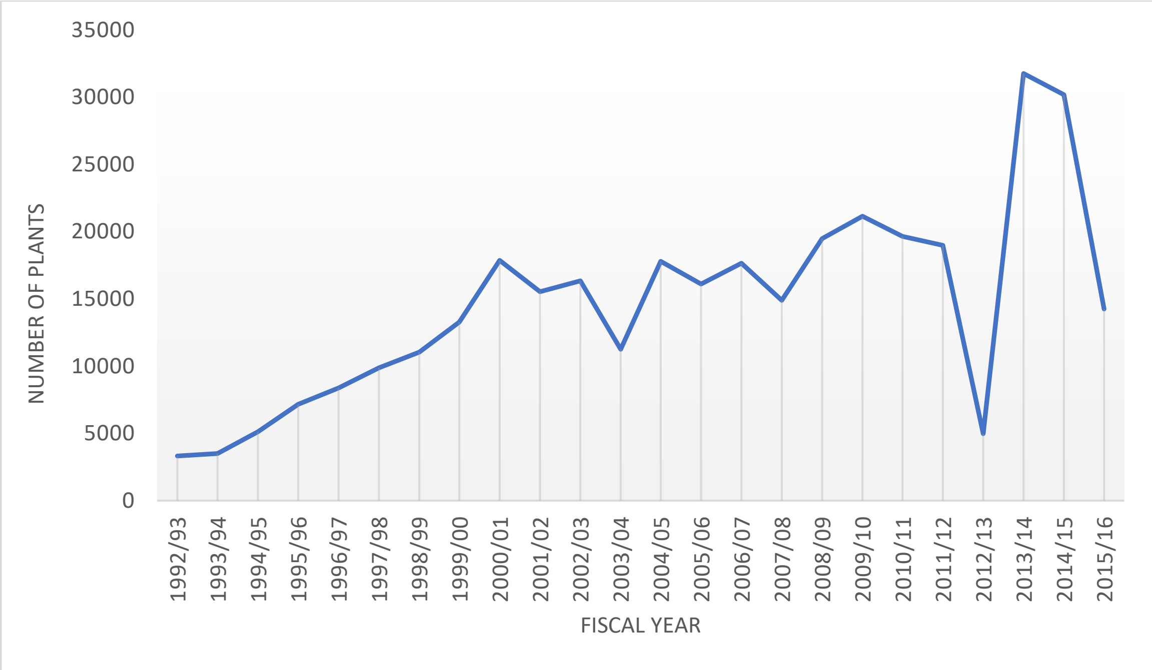

Figure 13: Year-wise installation of the biogas plant in Nepal (Aepc.gov.np, n.d.)

3.3.4 Special Waste Management

Special waste includes hazardous waste, medical waste, industrial waste, construction waste, demolition waste and waste from dead animals. This kind of waste must be treated separately and cannot be mixed with MSW. In Nepal, most of the hospitals practice incineration of medical waste within their premises in the open space or in the incineration chambers (Environment.org.np, 2004). The hospitals in Nepal mostly focuses on SWM predominantly done by incineration. The district hospitals and below level manages their waste poorly by incinerating, pit burning, or disposing them in the landfill along with MSW. The report from MoPH (Ministry of Health and Population), 2014 estimates that about 60% of big hospitals practices MSW disposal system. According to the report from MoHP, there are 92 governmental hospitals, 3 community hospitals, 14 teaching hospitals, 157 private hospitals, 8 mission hospitals and 274 country hospitals. These hospitals generate about 21 000 tonnes of healthcare waste (HCW) in a year, out of which about 6 100 tonnes of waste are hazardous or risk waste (HCRW). The detail on types of hospitals, their bed capacity, and waste generation are illustrated in table 2.

Table 2: Healthcare facilities and waste generation in Nepal (MoHP, 2014).

Types of hospital	Number of hospitals	Total beds	HCW (tonnes/year)	HCRW (tonnes/year)
Governmental Hospitals (under MoHP)	92	6601		
Governmental Hospitals (under another Ministry)	3	1036		
Private Hospitals	157	9207		
Private Teaching Hospitals	14	8626		
Mission Hospitals	8	612	246.83	72.60
Country Hospitals	274	26082	10519.51	3093.98
Government Total	95	7637	3080.19	905.94
Private Total	171	17833	7192.49	2115.44
Grand Total	548	52164	21039.02	6187.96

The total HCW from health institutions is estimated about 0.533 kg/bed/day, in which 0.256 kg/bed/day is a general non-hazardous waste and non-biodegradable waste. Biodegradable waste includes 0.147 kg/bed/day and infectious waste including sharps is 0.120 kg/bed/day. The hazardous chemical waste is 0.009 kg/bed/day. (UNEP, 2012) In Nepal few hospitals like Bir, Civil Service Hospital, Sahid Gangalal National Heart Centre, Manipal Teaching Hospital and Western Regional Hospital have started to manage medical waste in a safe way (MoPH, 2014).

The dead animals found is either buried or dumped by the municipal authority. The burying is made near to the riverbanks, open spaces and in the jungles. The survey by ADB revealed that the 23 municipalities buried the dead animals while 11 municipalities dumps them. No well-managed slaughterhouse is observed in any municipality (Adb.org.np, 2013).

The demolition and construction waste are also mixed with the municipal waste, burned, dumped and only a small share is treated. The scrap dealers however, collect some demolition waste which can be recycled. The Environmental Protection Act, 1997 states that no individual or industries shall produce any waste which harms the environment and public health. But the industries are not found practicing proper waste management system in Nepal.

4. WASTE TO ENERGY POSSIBILITIES IN KMC, A CASE STUDY

4.1 KMC at a Glance

Kathmandu is the capital city of Nepal with a total population of 1 744 240 according to the census of 2011. KMC along had the population of 975 453. In the census of 2001, the population of Kathmandu district was 1 081 845 (Cbs.org.np,2013). Although the population was only about 0.9 million the total population residing in KMC and its agglomerated district (Lalitpur, Kritipur, Madhyapur Thimi and Bhaktapur) namely as Kathmandu Valley is roughly around 2.5 million (World Bank, 2013). However, the people residing in KMC and its agglomerated districts is assumed much more because KMC being the capital of a country and most of the institutional, commercial and governmental offices locating here. The residents of Kathmandu Valley are expanding at the rate of 4% annually which is the highest growing metropolitan area in South Asia (World Bank, 2013).

KMC is the eldest metropolitan city of Nepal locating at an elevation of 1400m and is a bowl-shaped valley surrounded by four major mountains; Chandragiri, Nagarjun, Phulchowki, and Shivapuri. The location map of KMC and its neighbouring districts is illustrated in figure 14 below.

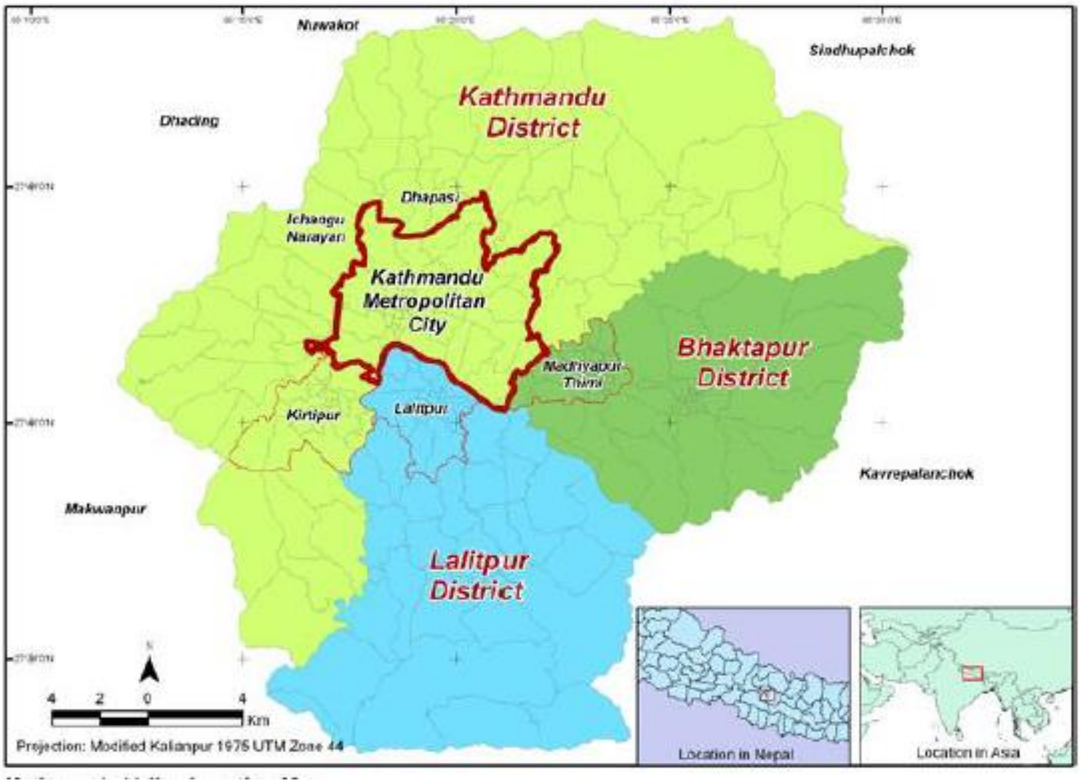

Figure 14: Location map of KMC and its neighbouring districts (UDM,2015).

4.2 Waste Management System in KMC

4.2.1 Waste Management System in The Past

In the past, before the 1980s the solid waste generated in Kathmandu was very low. Those waste generated were mostly composted at the household level as they were highly organic. Other waste was either recycled, reused or disposed to the open spaces. In 1981 due to urbanization and commercialization the German Society for International Cooperation (GTZ) established a SWM project. The Gokarna landfill site was the outcome of this project which came into operation in 1986.The Teku transfer station was established in the same year. The waste from KMC was collected and disposed of to the Gokarna landfill site. There were informal waste recyclers in the Teku transfer station who used to segregate the organic and material waste. The demand for the betterment and higher pay from the informal waste recyclers led to the clash between worker and KMC which result in the eviction. GTZ also constructed the composting plant which stopped its operation in 1992 because it was unable to separate the glass from the waste. The increasing urbanization and commercialization led to the establishment of SWMRMC which is now called as SWMTRC. After the establishment of SWMRMC, the financial and technical support from GTZ was decreased and the management of Gokarna landfill site was transferred to the SWMRMC. The Gokarna landfill site being operated for 14 years was closed in the year 2000 because of the improper management and strong criticism from the local people (Singh, et.al, 2014).

4.2.2 Waste Management System in The Present

After the implementation of Local Self Governance Act of 1999, all municipalities and village development committees are responsible for the management of MSW at the local level. Kathmandu Metropolitan City (KMC) after its establishment in 1919, it has the main responsibility in managing the waste of the area from collection to final disposal. The flow chart illustrating the waste management system practiced in KMC is shown in figure 15. The waste generated in Kathmandu metropolitan area is either unmanaged, recycled, composted, or disposed to landfill site. The unmanaged waste is usually thrown in the roadside, open spaces or to the river banks. Some amount of waste is recycled which is collected by the informal waste collector. It is estimated that there are 800 scrap shops collecting recyclable waste only in Kathmandu Valley. Composting is also practiced in few amounts while most of the waste is collected and transferred to the landfill site. The waste collected is directly disposed of to the landfill site or is taken to the transfer station (Teku transfer station). The LFG generated in the landfill site is not collected for recovery options. The household waste is collected either door to door, collected by vehicle from a container or is collected from the roadside. (Ranabhat, 2015).

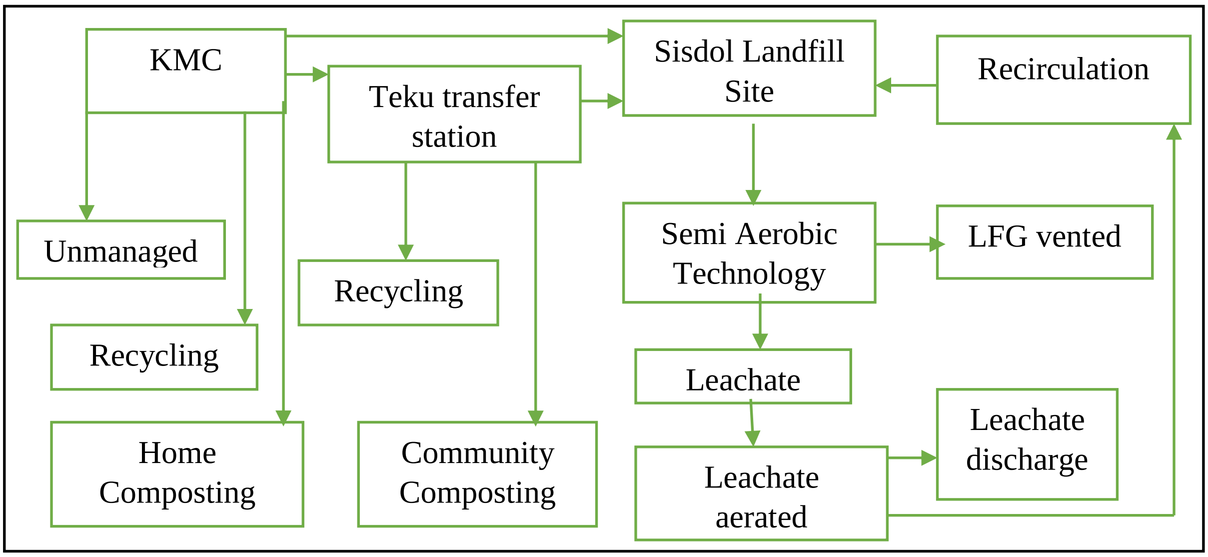

Figure 15: SWM system in Kathmandu (Ranabhat, 2015).

KMC collaborates with PSOs (Private Sector Organizations) for waste collection. Out of 35 wards KMC collects waste from 12 wards, PSOs collects waste from 1 ward and jointly KMC and PSOs collect waste from 22 wards (UDM,2015). KMC operates 7 trucks, 1 power trailer and 130 manual carts for the collection of waste which is operated in 134 various routes. The number of trucks were found unused during the field visit to the Environment department of KMC by UDM. According to the KMC, the household waste is collected daily, however during the field visit householders says, the waste is collected 2 or 3 times a week (Oagnep.gov.np, 2015). KMC provides bigger containers for waste collection from institutional and commercial waste producers. The type of institutions and their numbers where KMC provides a bigger container for waste collection is depicted in table 3.

Table 3: Number of institutions where KMC provides its service (UDM,2015).

Type of institutions	**Numbers**
Government offices	11
Business complex	2
Educational institution	2
Hotel/Restaurant	1
Hospitals	10
Embassy	2
Total	28

The number of containers provided for waste collection is clearly much low since there are many more commercial institutions, schools, hospitals, embassies, hotels, and restaurants. Although KMC provides a container for waste collection, no separate containers are provided for segregating the waste at source. Beside KMC the MSW generated is collected by the private sector, NGOs (Non-governmental organizations), community-based organizations and youth clubs (Alam, et.al, 2007). There is a substantial increase in the participation of private organization for the collection of MSW generated in Kathmandu. Table 4 depicts the waste generation and involvement of private organization for MSW collection in Kathmandu in the different year.

Table 4: Waste generation and collection by the private sector in KMC (Alam, et.al, 2007).

Year	Waste generation (m^3/day)	Waste collected by private sector (m^3/day)	Waste collected by private sector in %
2000	944	116	17
2001	949	130	20
2002	975	244	27
2003	1008	252	27

KMC has an agreement with about a dozen of private companies for street sweeping, collecting waste and transporting waste from various areas of the city (Adb.org, 2013).

Teku Transfer Station

Teku transfer station is the only one transfer station operated by KMC. According to the Solid Waste Management Act of 2011, the local bodies can fix any location for the primary collection of solid waste taking into consideration that there is no severe effect in the environment and public health and the necessary measures shall be taken to control the bad odours. The partial amount of waste collected in KMC is transferred to the Teku transfer station where waste is collected and compressed. The transfer station has the capacity of 10,000 tonnes where waste is collected in the open space surrounded by the residential area. The transfer station was constructed with a facility of segregation and composting, but it is not operating now because of managerial complication. The transfer station faces a huge problem of transferring collected waste forward especially when the Sisdol landfill site is closed temporarily due to many reasons. The residential people around the transfer station faces the problem of bad odour and health. The leachate produced from the transfer station is directly passed to the Bishnumati river. According to the audit interview taken by UDM with 48 people within 300m of transfer station during survey they found that 100% of people have complained about bad odour, 92% of people suffered from respiratory problems, 96% agreed about the environmental degradation, 96% recommend for the close of transfer station and 98% of people said the waste is not collected on time. (Oagnep.gov.np, 2015)

Transportation

According to the Solid Waste Management Act, 2011 KMC is responsible for the transportation of waste collected to the transfer station and disposal site. The vehicle used for the transportation shall be specific and the weight, age, capacity, impact on the environment during transportation shall be taken into consideration while transporting. Currently, KMC obtains 21 vehicles and hires other private vehicles if necessary. These existing vehicles have the problem of waste falling out due to overload, odour along the way during transportation and maintenance problem (UDM,2015). KMC uses different vehicle for primary waste collection and secondary waste transportation (Apo-tokyo.org, 2007). The waste collected by primary vehicle is transferred to the transfer station where waste is loaded to the secondary vehicle using a loader.

3R's of Waste Management

According to the Solid Waste Management Act, 2011 any individual, firm or organization shall reduce the production of solid waste at source. And the local body shall encourage the 3R's of waste management by implementing necessary directives and coordinating with the concerned industries and organizations. But KMC at present has neither issued any directives for waste reduction nor operated any composting facility and recycling centres (Oagnep.gov.np, 2015).

Final Disposal

The waste collected in the Teku transfer station and waste collected by primary vehicles is disposed of to the Sisdol landfill site. The Sisdol landfill site is the only one landfill site in KMC which is located about 28 km away from Kathmandu (Apo-tokyo.org, 2007). The Sisdol landfill site was constructed with the help of JICA and is constructed according to the Fukuoka semi-aerobic principle. The landfill site is fitted with a clay liner and a system with leachate recirculation. The waste fraction disposed of is decomposed at the faster rate by regularly aerating the leachate being collected by an aerator system (Ranabhat, 2015). The longitudinal profile of leachate treatment plant in Sisdol landfill site is illustrated in figure 16.

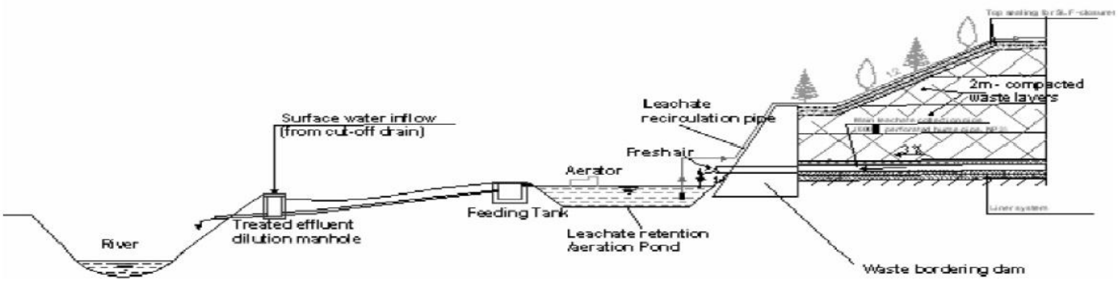

Figure 16: Longitudinal profile of leachate treatment plant (Ranabhat, 2015).

The landfill site with a capacity of holding 275 000 tonnes of waste came into operation from June 5, 2005 (JICA, n.d.). The landfill site was designed for 2-3 years; however, it is still into operation after an expansion work carried out by SWMTSC. A new landfill site in Banchare Dada in Nuwakot district is under construction since Sisdol landfill site is running out of its capacity.

4.3 Stakeholders

Various stakeholders are associated in the financial and technical management of MSW generated in Kathmandu Valley. Figure 17 below depicts, the different organization involved in the SWM. At policy level Ministry of Local Development (MOLD) is responsible for the management of solid waste. MOLD coordinates with other line ministries namely; Ministry of Education Science and Technology (MOEST), Ministry of Health and Population (MOHP), Ministry of Industry Commerce and Supplies (MOICS) and other ministries. According to the Local Self Governance Act, 1999 the local bodies are responsible for management of solid waste at an operational level. The local bodies of Kathmandu Valley include Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), Bhaktapur Municipality (BKM), Madhyapur Thimi Municipality (MTM) and Kritipur Municipality (KRM). The local body, distinctively municipality have the separate waste management unit which is either a division of Planning and Urban Development Section or Community Welfare section (Environment.org.np, 2004). SWMRMC established under GTZ is responsible for providing technical assistance which is now called as SWMTSC. SWMRMC board formed in 1987 evaluates the work done by SWMRMC.

The national council on SWM was formed along with the Solid Waste Management National Policy, 1996 which is an ultimate body to make plans and policies. The MOLD and line ministries act as a supporting arm for national council.

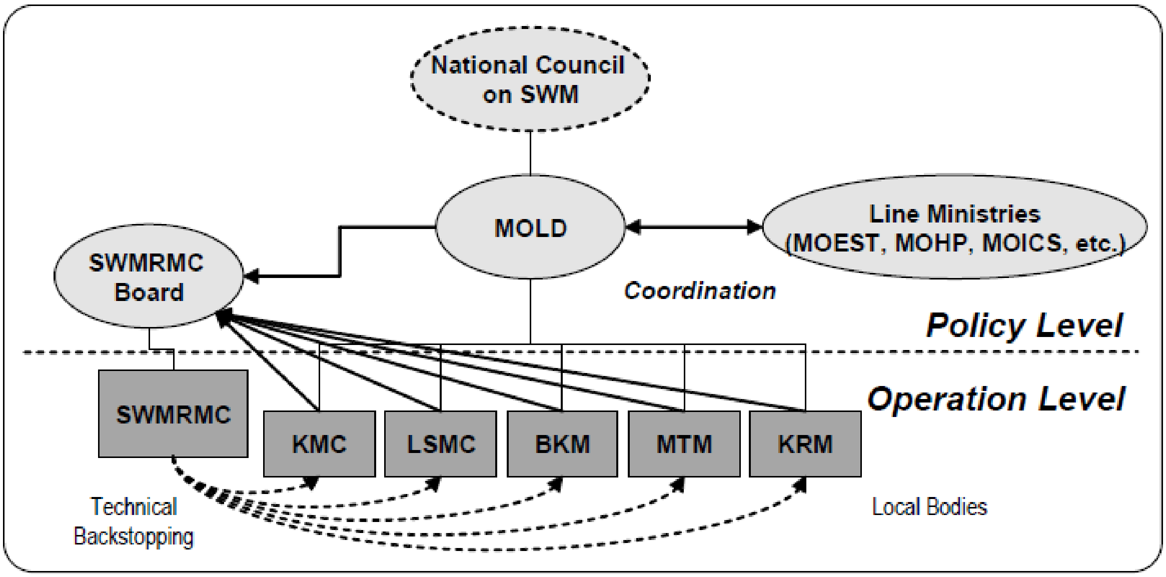

Figure 17: Various stakeholders involved in the SWM of Kathmandu Valley (JICA, 2005).

4.4 Resource Allocation for SWM

The efficient and effective waste management system requires allocation of financial and technical resources in a substantial manner. The number of human resources, technical abilities, and financial allocation differs significantly among the municipalities of Nepal. It is estimated that about 10% of the total municipal budget is allocated for SWM. The highest amount of money in KMC is disbursed on solid waste collection and street sweeping which accounts for about 60-70%, transportation system accounts for 20-30% and remaining amount in the final disposal (Adb.org.np, 2013). This data indicates that there is a necessity to reduce financial expenditure in the collection system, manage it effectively and increase the amount in a final disposal. The budget allocation for SWM of KMC for the fiscal year 2010-2012 is shown in table 5.

Table 5: Total Municipal Budget and SWM Budget in KMC (Adb.org.np, 2013)

1 € = 121.17 NRs as of 21/12/2017 (Nepal Rastra Bank)

Fiscal Year	Total Municipal Budget (NRs Million)	Total SWM Budget (NRs Million)	SWM Budget in %
2010	1212.85 (10 Million €)	278.61 (2.29 Million €)	22.97
2011	947.41 (7.8 Million €)	253.13 (2.08 Million €)	26.72
2012	1900 (15.6 Million €)	443.10 (3.65 Million €)	23.32
Average		324.94 (2.68 Million €)	24.34

The average SWM budget is about 24% of the total municipal budget, which is a satisfactory amount compared to that of a total municipal budget. However, it is found that the total SWM budget is not consumed (Oagnep.gov.np, 2015). For the fiscal year of 2011/2012, 86% of the total allocated budget was disbursed. Similarly, for the fiscal year 2012/2013 it was 83% and, for 2013/2014 it was 65%. KMC has a separate department to manage the solid waste generated. The report from UDM, 2015 states that there is 1,111 number of human resource involved in the waste management of KMC. The highest number of human resource are sweepers.

The monitoring and follow up activities are necessary for effective management of MSW. KMC has formed a 6-member committee to monitor activities related to the SWM. The members are from MOLD, Ministry of Health and Population, Ministry of Environment, Ministry of Urban Development, Ministry of Science and Technology and SWMTSC. The analysis from UDM, 2015 has found that no monitoring activities have been performed since its establishment.

4.5 Materials and Methods for The Case Study

The data required for the case study is extensively taken from the literature. KMC is chosen as the location for the case study. The waste composition collected is either composted, incinerated, landfilled with landfill gas recovery, anaerobically digested or recycled in different scenarios. Electricity is generated from various energy recovery methods and is compared within each other. Although CHP (Combined Heat and Power) generation is the efficient option, CHP generation is not covered since there is an absence of household heating system in Nepal and no abundant industries using heat for various purposes. Composting is done to produce quality compost and to decrease the volume of the organic waste. Recycling is done to decrease the impact on the environment and to decrease the need for virgin raw material for the production. The net GHGs emission from different waste management option is also calculated. The methodological approach for the case study of waste management in KMC is depicted in figure 18.

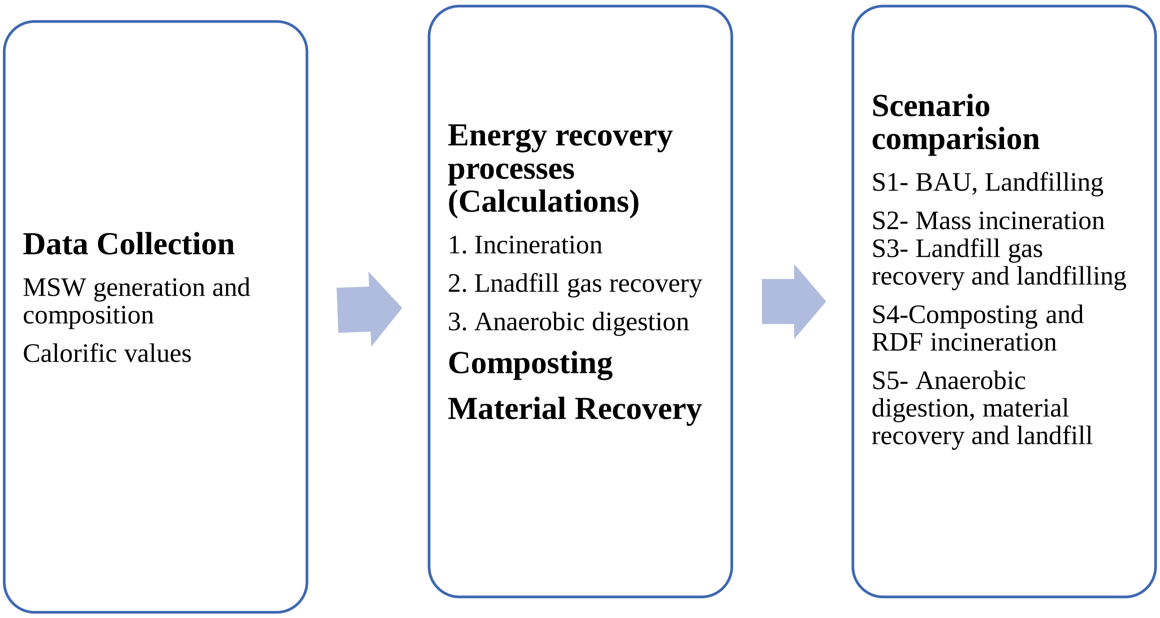

Figure 18: A methodological approach for the case study.

4.5.1 Waste generation and its composition

According to the Environment Audit report of UDM, 2015 the estimated MSW generation of KMC per day is 516 tonnes. The annual estimated MSW generation accounts for about 188 340 tonnes and MSW generation per capita in KMC accounts for 300g per day (Oagnep.gov.np, 2015). The highest amount of waste composition is organic followed by plastics and paper. The waste collection efficiency of KMC is estimated to be 86.9% (Adb.org, 2013). The chronological data on the waste composition of Kathmandu Valley and KMC is illustrated in table 6. The waste composition data of the year 2015 is considered for the calculation in this thesis work.

The calculation of electricity generation and GHGs emission from waste fractions of the scenarios is based on the available data for the year 2015. The waste fractions are segregated and prepared according to the requirements of various scenarios. The emission from the waste fractions are not calculated for the whole life cycle of waste management but only the main source is considered. The emission calculations are mostly based on the guidelines provided by Intergovernmental Panel on Climate Change, 2006.

Table 6: Waste composition of Kathmandu Valley and KMC in chronological order.

Components		**Waste composition in %**									
	a1976	a1981	a1985	a1988	a1995	a1999	a1997	a2000	a2003	a2013	b2013	c2015
Organic Waste	67.8	60	67.5	58.1	65	67.5	65.5	69.84	70	73.22	53.25	63.22
Plastics	0.3	3.6	2.6	2.0	5	11.4	5.4	9.17	9.5	11.43	20.14	10.8
Paper	6.5	19.3	6	6.2	4	8.8	7.3	8.5	8.5	6.89	17.28	9.02
Glass	1.3	3.4	4	1.6	1	1.6	3.1	2.5	2.5	2.10	3.21	5.42
Metals	4.9	3.4	2.2	0.4	1	0.9	2.2	-	-	1.06	2.08	0.42
Textiles	6.5	5.3	2.7	2	3.0	3.6	1.7	3.02	3	1.61	2.39	2.3
Rubbers	0	0	0	0.4	1	0.3	1.6	0.6	-	0.62	0.64	1.2
Wood	2.7	1.6	0	0.5	3	0.6	1.4	0.73	-	-	-	-
Construction and demolition	10	3.4	15	2.89	17	5.3	9.1	-	4.5	-	-	4.5
Others	-	-	-	-	-	-	1.7	0.23	2	3.07	0.96	1.2

Kathmandu Valley; (KMC, LSMC, Bhaktapur, Thimi and Kritipur municipality)

a- CBS, 2015 Waste composition of Kathmandu Valley

b- Adb.org, 2013 Waste Composition of KMC

c- UDM, 2015 Waste Composition of KMC

4.5.2 Mass incineration

For mass incineration, all municipal waste composition collected is taken to the incineration facility without any pre-treatment. Lower heating value as received LHV_{ar} is used to express the energy released during a combustion process. Due to lack of sufficient data on LHV of MSW composition in KMC, the average LHV from similar country and city with close income level, waste composition, and generation is taken into consideration. LHV of MSW composition in the Philippines, Manila, Bangladesh and Indonesia is taken into consideration. To carry out the combustion process the average net calorific value must be at least 7 MJ/kg and must never fall below 6 MJ/kg (ISWA, 2013). From table 7 below we can see that the average LHVar for moist mass of MSW composition is estimated to be 4,07 MJ/kg. This indicates that the combustion process is not self-sustaining and to carry out the combustion process, high energy content fuel must be added. Coal is added to the system with an energy content of 28 MJ/kg (Lohani, 2012). To get an average net calorific value of 7 MJ/kg, about 63 tonnes of coal with an energy content of 28 MJ/kg must be added to the system. Now the system must be designed to incinerate 511,38 tonnes/day waste. The waste collection efficiency is assumed to be 86,9% and electricity generation efficiency for mass incineration facility is in the range of 15-27% (Worldenergy.org, 2016). The average value of 21% is considered here for the calculation.

Table 7: Calculation of LHVar for moist mass of MSW composition.

Waste Components	Waste Composition (%)	LHV_a (MJ/kg)	LHV_b (MJ/kg)	LHV_c (MJ/kg)	LHV (Average) (MJ/kg)
Organic Waste	63,22	1,91	0,96	2,89	1,92
Plastics	10,8	20,14	-	-	20,14
Paper	9,02	6,44	3,45	1,51	3,80
Glass	5,42	-0,07	0,03	0	-0,01
Metals	0,42	-0,15	0,14	0,01	0
Textiles	2,3	11,79	3,59	0,07	5,15
Rubbers	1,2	14,27	-	-	14,27
Construction and demolition	4,5	-	-	0,05	0,05
Others	1,2	-	1,44	-	1,44
Weighted average					**4,07**

LHV_a = Lower heating value of MSW composition in the Philippines, Manila (Source; Rand, Haukohl and Marxen, 2000)

LHV_b = Lower heating value of MSW composition in Bangladesh (Source; Islam, 2016)

LHV_c = Lower heating value of MSW composition in Indonesia (Source; Gramse and Christia, 2010)

Note: The LHVar of plastic from Bangladesh and Indonesia is not taken into consideration as they are being highly unreliable.

The required data for the calculations such as; weight of the waste composition, heating values, yearly waste generation and collection and energy content is illustrated in table 8. The energy content and electricity generation from the waste composition is calculated using equation 1 and 2 where,

η_e = Electricity generation efficiency

$$Energy\ Content = LHV * Total\ Mass\ of\ the\ Waste \tag{1}$$

$$Electricity\ generation = \eta_e * Energy\ Content \tag{2}$$

The total energy content by the system annually is about 363 000 MWh and the electricity generation capacity annually are about 76 300 MWh.

Table 8: Energy content in the MSW Composition.

For MSW					
Waste Components	Daily waste generation (tonnes)	Average weighted lower heating value (MJ/kg)	Daily waste collection with 86.9% efficiency (tonnes)	Total waste collection yearly (tonnes)	Energy Content (MWh)
Organic Waste	326,22		283,49	103 472	
Plastics	55,72		48,42	17 674	
Paper	46,54		40,44	14 762	
Glass	27,96		24,30	8 868	
Metals	2,17		1,89	688	
Textiles	11,87		10,32	3 765	
Rubbers	6,19		5,38	1 963	
Construction and demolition	23,22		20,18	7 365	
Others	16,07		13,96	5097	
Total	**515,96**	**4,07**	**448,37**	**163 655**	**185 000**

For coal		
Total coal used in a year (tonnes)	Calorific value of coal (MJ/kg)	Energy Content (MWh)
22995	28	178 850

Total energy content in the system (MWh)	**363 000**
Electricity generation capacity from MSW	**38 800**
Electricity generation capacity from coal	**37 500**
Total electricity generation capacity annually (MWh)	**76 300**

Emission calculation from mass incineration

The incineration of MSW along with coal releases significant amount of carbon dioxide (CO_2) in the atmosphere. As suggested by the IPCC, 2006 only fossil-based waste fraction are considered for the calculation of the GHGs (Greenhouse gases) emission. The MSW consist of a mixed waste fraction where the distinction between carbon of biogenic origin and fossil origin is identified. The only waste fraction of fossil origin such as; plastics, textiles, rubbers and construction and demolition waste are taken into consideration (Table 9). The emission from biogenic origin such as; organic waste and paper is not considered for the calculation and inert fractions with glass and metal is not taken into consideration as they don't contain combustible or carbon which would burn to CO_2. The total GHG emission is estimated by calculating three major GHG_s; CO_2, methane (CH_4), and nitrous oxide (N_2O). The calculated amount of CH_4 emission and N_2O emission is converted to a CO_2 equivalent by multiplying by the factor of 25 and 298 respectively. The GWP_{100} (Global Warming Potential) is the sum of all three major GHG_s.

Table 9: Waste fractions considered for emission calculation.

Waste Components	Lower heating value (MJ/kg)	Share of waste fraction out of total MSW (%)	Total waste incinerated yearly (tonnes)
Plastics	20,14	10,8	17 674
Textiles	5,15	2,3	3 765
Rubbers	14,27	1,2	1 963
Construction and demolition	0,05	4,5	7 365
Total			**30 767**
Weighted average	**13,31**		
Coal	28		**22 995**

The total amount of 30 767 tonnes of non-biogenic waste fraction i.e. about 19% of incinerated MSW is responsible for the emission of GHG_s. The weighted average LHV of a non-biogenic waste fraction is 13,31 MJ/kg. In addition, 22 995 tonnes of coal with LHV of

28 MJ/kg is responsible for the emission of GHG_s. Equation 3 and 4 below is used to calculate the amount of emission from non-biogenic waste fraction and coal.

$$Emission_{non-biogenic} = (Fuel\ consumed * LHV_{non-biogenic} * EF)/10^6 \quad (3)$$

$$Emission_{coal} = (Fuel\ consumed * LHV_{coal} * EF)\ /10^6 \quad (4)$$

Where,

$Emission_{non\text{-}biogenic}$ = Amount of CO_2, CH_4 and N_20 emission (kg/a) from non-biogenic waste

$Emission_{coal}$ = Amount of CO_2, CH_4 and N_20 emission (kg/a) from coal

Fuel consumed = Total fuel incinerated in a year (kg/a)

$LHV_{non\text{-}biogenic}$ = Energy content by the fuel (MJ/kg)

LHV_{coal} = Energy content by the coal (MJ/kg)

EF = Default emission factor for CO_2, CH_4 and N_20. Taken from figure 19.

10^6 = Conversion of MJ into TJ

The default value of emission factor for non-biogenic MSW is illustrated in figure 19.

TABLE 2.2 (CONTINUED)
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE ENERGY INDUSTRIES
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH_4			N_2O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Municipal Wastes (non-biomass fraction)		n 91 700	73 300	121 000	30	10	100	4	1.5	15
Industrial Wastes		n 143 000	110 000	183 000	30	10	100	4	1.5	15
Waste Oils		n 73 300	72 200	74 400	30	10	100	4	1.5	15
Peat		106 000	100 000	108 000	n 1	0.3	3	n 1.5	0.5	5
Solid Biofuels	Wood / Wood Waste	n 112 000	95 000	132 000	30	10	100	4	1.5	15
Solid Biofuels	Sulphite lyes (Black Liquor)[a]	n 95 300	80 700	110 000	n 3	1	18	n 2	1	21
Solid Biofuels	Other Primary Solid Biomass	n 100 000	84 700	117 000	30	10	100	4	1.5	15
Solid Biofuels	Charcoal	n 112 000	95 000	132 000	200	70	600	4	1.5	15
Liquid Biofuels	Biogasoline	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
Liquid Biofuels	Biodiesels	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
Liquid Biofuels	Other Liquid Biofuels	n 79 600	67 100	95 300	r 3	1	10	0.6	0.2	2
Gas Biomass	Landfill Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
Gas Biomass	Sludge Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
Gas Biomass	Other Biogas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
Other non-fossil fuels	Municipal Wastes (biomass fraction)	n 100 000	84 700	117 000	30	10	100	4	1.5	15
Other Bituminous Coal		94 600	89 500	99 700	1	0.3	3	r 1.5	0.5	5

(a) Includes the biomass-derived CO_2 emitted from the black liquor combustion unit and the biomass-derived CO_2 emitted from the kraft mill lime kiln.
n indicates a new emission factor which was not present in the 1996 Guidelines
r indicates an emission factor that has been revised since the 1996 Guidelines

Figure 19: Default emission value for non-biogenic waste fraction and coal (Source; IPCC,2006).

The default emission factor for coal is taken of bituminous coal whose average heating value is around 28 MJ/kg (Engineeringtoolbox.com,n.d.). The total emission by the mass incineration system is the sum of equation 3 and 4.

$$Emission_{total} = Emission_{non-biogenic} + Emission_{coal} \tag{5}$$

Using equation 3, Calculating GHG_s emission from the non-biogenic waste fraction.

CO_2 emission from non-biogenic waste fraction.

$$\text{Emission CO2}_{(\text{non-biogenic})} = \frac{(30767 * 1000)\text{kg} * 13{,}31\text{MJ/kg} * 91700\text{kg/TJ}}{10^6}$$

$$= 3{,}76 * 10^7 \ kg\ CO2 - \ \text{equiv./a}$$

CH_4 emission from non-biogenic waste fraction.

$$\text{Emission CH4}_{(\text{non-biogenic})} = \frac{(30767 * 1000)\text{kg} * 13{,}31\text{MJ/kg} * 30\text{kg/TJ} * 25}{10^6}$$

$$= 3{,}07 * 10^5\ kg\ CO2 - \text{ equiv./a}$$

N_2O emission from non-biogenic waste fraction.

$$\text{Emission N2O}_{(\text{non-biogenic})} = \frac{(30767 * 1000)\text{kg} * 13{,}31\text{MJ/kg} * 4\text{kg/TJ} * 298}{10^6}$$

$$= 4{,}88 * 10^5\ kg\ CO2 - \text{ equiv./a}$$

Total GHG_s emission from non-biogenic waste fraction is 3,84E+07 kg CO_2 – equiv./a

Now,

Calculating GHG_s emission from coal.

CO_2 emission from coal.

$$\text{Emission CO2}_{(\text{coal})} = \frac{(22995 * 1000)\text{kg} * 28\text{MJ/kg} * 94600\text{kg/TJ}}{10^6}$$

$$= 6{,}09 * 10^7\ kg\ CO2 - \text{ equiv./a}$$

CH_4 emission from coal.

$$\text{Emission CH4}_{(\text{coal})} = \frac{(22995 * 1000)\text{kg} * 28\text{MJ/kg} * 30\text{kg/TJ} * 25}{10^6}$$

$$= 4{,}83 * 10^5\ kg\ CO2 - \text{ equiv./a}$$

N_2O emission from coal.

$$\text{Emission N2O}_{(\text{coal})} = \frac{(22995 * 1000)\text{kg} * 28\text{MJ/kg} * 4\text{kg/TJ} * 298}{10^6}$$

$$= 7{,}67 * 10^5\ kg\ CO2 - \text{ equiv./a}$$

Total GHG_s emission from coal is 6,22E+07 kg CO_2 – equiv./a.

The total GHG_s emission during the combustion process is the sum of emissions from non-biogenic waste fraction and coal which is 1,01E+08 kg CO_2 – equiv./a. Hydroelectricity is the predominant energy source in Kathmandu. The hydropower generation emits about 11,3 g CO_2 per kWh throughout its entire life cycle (Honda, 2005). The highest share of emission is during the construction phase. Producing the same amount of electricity as produced by mass incineration process through hydropower generation emits about 8,39E+05 kg CO_2 – equiv.

4.5.3 Landfill gas recovery

For landfill gas recovery and its utilization, the collected amount of waste fractions is disposed of to the landfill site and the amount of methane generated is collected. For the calculation of methane gas generation mass balance method i.e. IPCC Default Method (DM) is used. Equation 6 below employed by Bingermer and Crutzen and recommended by IPCC 1996 is implemented here to calculate the amount of methane emission. The DM assumes that all the potential methane generation is released in the same year the solid waste is disposed of. The calculation method does not estimate the potential time dependence methane generation and the effect of MSW addition in the landfill are not taken into consideration over time. Some of the empirical constants like MCF, F and DOC have been used as provided by IPCC. The average annual temperature of Sisdol landfill site is taken to be 18°C (Pokhrel and Viraraghavan, 2005) and the landfill is supposed to be under daily soil cover with a methane collection rate of 60% (Epa.gov, 2011). The degradable organic carbon (DOC) in organic waste fraction is taken to be 0,15 kg carbon per kg of waste and for other waste fractions the DOC is depicted in table 18 in section 4.5.8. The electricity generation potential from methane gas collected is taken to be 30% and is assumed to be combusted in the reciprocating engine as suggested in the report "Evaluation of energy potential of Municipal Solid Waste from African urban areas" (Scarlat et.al., 2015).

$$m_{CH4} = (MSW_T * MSW_F * MCF * DOC * DOC_F * F * \frac{16}{12} - R) * (1 - OX) \qquad (6)$$

Where,

m_{CH4} = The mass of methane emission (t/a)

MSW_T = The total amount of MSW generated and collected (t/a), taken to be 163600 t/a

MSW_F = Share of waste disposed to the landfill (taken to be 0.6322)

MCF = Methane correction factor (0.6)

DOC = Degradable organic carbon

DOC_F = Fraction of DOC dissimilated

$$DOC_F = 0{,}014T + 0{,}28 = 0{,}53 \tag{7}$$

F = Fraction of methane gas in landfill (0.5)

16/12 = Conversion of C to CH_4

R = Recovered CH_4 (Default value is 0)

OX = Oxidation factor (Default value is 0)

Now CH_4 generated from the landfill.

$$m_{CH4} = (163600\text{ t/a} * 0{,}6322 * 0{,}6 * 0{,}15 * 0{,}53 * 0{,}5 * \frac{16}{12} - 0) * (1 - 0)$$

$$m_{CH4} = 3290\text{ t/a}$$

The amount of methane emitted in a year from organic waste fraction is 3 290 tonnes and the emission from other waste fraction is calculated in a similar manner as for organic waste fraction and is shown in table 19 below in section 4.5.8. The total amount of methane emission from MSW fraction disposed to landfill is 5 141 tonnes per year. With methane collection rate of 60% the total amount of methane collected is 3 085 t/a. The average LHV of methane gas is 50 MJ/kg (Engineeringtoolbox.com,n.d.). Now, by using equation 1 and 2 the electricity generation annually from methane gas recovered is about 12 853 MWh.

Emission calculation from landfill gas recovery

During the landfilling process of MSW, not all methane gas is captured for energy recovery. A certain amount of landfill gas is oxidized in the upper layer of the landfill and the remaining landfill gas which is not captured is released into the atmosphere. To calculate the amount of methane gas emitted in a year, the IPCC, FOD (First Order Decay) method is implemented in this report.

$$CH_4\ emitted\ in\ a\ year = (CH_4\ generated\ in\ a\ year - CH_4\ recovered\ in\ a\ year) * (1 - OX)$$

Where,

OX = Oxidation factor

The oxidation factor of 0.1 is used here and the landfill site is assumed to be well managed.

Using above equation, the annual CH_4 gas emitted in the atmosphere during landfill gas recovery process is 1851 tonnes annually.

The CO_2 – equiv./a emission is 4,63E+07 kg.

Sensitivity Analysis

The quantity of electricity generation and CO_2 emission in the atmosphere significantly depends upon the methane collection efficiency. Depending upon the type of collection systems and various cover materials the LFG collection efficiencies varies a lot (Epa.gov, 2011). Table 10 below depicts the type of landfill cover material, its collection efficiency, electricity generation potential with efficiency of 30% and CO_2 emission in the atmosphere. The estimated values of electricity generation and CO_2 emission is compared with the calculated value with collection efficiency of 60% in figure 20 with daily soil cover. As seen in figure 20 it is possible to increase the electricity generation potential by 58% and decrease the CO_2 emission by 88% compared to the initial values with efficiency of 60%.

Table 10: Electricity generation potential and CO2 emission based on gas collection efficiency (Epa.gov, 2011).

Type of landfill cover material	Gas collection efficiency (%)	Total amount of CH_4 collected (tonnes/year)	CH_4 emitted in a year (tonnes)	Electricity generation potential (MWh)	CO_2 emission in a year (kg CO_2 equiv.)
Operating cell (No final cover)	35	1 799	3 007	7 497	7,52E+07
Daily soil cover	60	3 085	1 851	12 853	4,63E+07
Intermediate soil cover	75	3 856	1 157	16 066	2,89E+07
Final soil cover or Geomembrane cover systems	95	4 884	231	20 350	5,78E+06

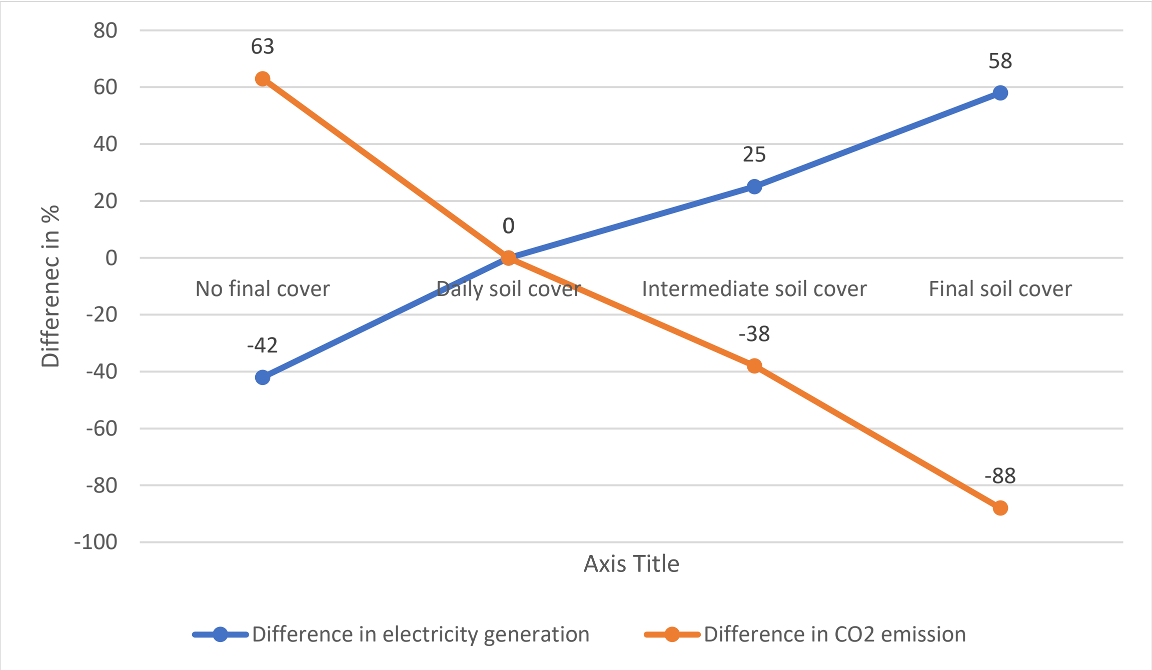

Figure 20: Relative difference in electricity generation and CO2 emission compared to daily soil cover.

4.5.4 Anaerobic digestion (AD)

The production rate of biogas from AD process depends upon several elements such as; pH value, temperature, feedstock characteristic, retention time, reactor design and operating condition. The optimal range of pH value for biogas production is 6,8-7,2. The average temperature for mesophilic AD process is 35°C and for the thermophilic process it is 55°C. Another factor affecting the rate of biogas production is C/N ratio in a solid waste. The solid waste with higher C/N ratio is not favourable for bacterial growth due to lack of nitrogen content. Likewise, the less C/N ratio leads to the accumulation of ammonia which is toxic to bacteria. The range of 25-30 is considered as the suitable C/N ratio for an AD. The other factor such as mixing condition and presence of inhibitory substances also plays an important role. (Nayono, 2009).

In this case study, it is assumed that only about 45% of the total organic waste fraction can be collected through separate waste collection system (Havukainen, Heikkinen and Horttanainen, 2016). A simple equation suggested by AEPC in "Biogas calculation tool user's guide" is implemented here for the calculation of biogas yield.

$$Biogas\ yield\ \left(\frac{m^3}{kg\ of\ waste}\right) = Biogas\ yield\ \left(\frac{m^3}{kg\ of\ VS}\right) * TS(\%) * VS(\%) \qquad (8)$$

Where,

TS = Total organic solid

VS = Volatile solid

The AEPC suggests biogas yield of 0,35 m^3/kg of VS which contains 75% of methane gas which is further used for the generation of electricity. According to the experiment carried out by Adhikari, Khanal and Miyan, 2015 in Sisdol landfill site, the average estimated moisture content by the solid waste is 69% and the percentage of the volatile solid is 44,41%. Using this information, and equation 8 above the table 11 below is created. The generated amount of methane gas in a year is used to produce electricity with an efficiency of 30% and it is assumed that complete combustion occurs without any methane slip.

The average LHV of methane gas is 35,8 MJ/m^3(Engineeringtoolbox.com,n.d.). Now, using above equation 1 and 2 the electricity generation annually is about 5 740 MWh.

Table 11: Estimation of methane gas generation in a year

Amount of organic waste generated (t/day)	Amount of organic waste collected for AD (t/day)	Moisture content	Total solid (TS) (t/day)	% of VS	Biogas yield (m^3/kg of VS)	Biogas yield (m^3/kg of waste)	Total biogas yield from organic waste (m^3/a)	Methane gas potential (m^3/a)
326,22	146	69%	45,26 (31%)	44.41%	0,35	0,0482	2568578	1926433

Emission calculation from AD

The total amount of biogas produced by the AD process is about 2 568 578 m^3 including 1 926 400 m^3 methane. The biogas is used in electricity production. The CO_2 emission from the electricity production process is not considered since organic waste is of the biogenic origin. The N_2O emission from the process is negligible and is not considered in this emission calculation process. (IPCC, 2006).

The amount of emitted CO_2 annually by the AD process depends upon the amount of methane slip during combustion process. Methane slip is the result of incomplete combustion in the engines. According to IEA, 2017 the average amount of methane slip is 1,89% of the total methane utilized for combustion process. (Liebetrau et al., 2017)

Using this information, the total amount of methane emitted annually is about 36 400 m^3. The density of CO_2 gas is 1,977kg/m^3 and the total emission per annum is 7,19E+04 kg.

Sensitivity analysis

There are several factors which affects the generation of methane gas in AD process. The total amount of organic waste fraction taken for AD process is a predominant factor which affects in the amount of biogas produced. In the above calculation the 45% of total organic waste fraction generated is assumed to be collected. Increasing the collection rate of organic waste fraction will increase in the amount of biogas produced and vice versa. Now, let us calculate the quantity of electricity generation and CO_2 emission by increasing the rate of collection to 60% and 75% and keeping other constraints similar. Table 12 below depicts the amount of electricity generation and CO_2 emission with increased collection rate. The higher the amount of organic waste fraction in AD process higher is the electricity generation and emission.

Table 12: Electricity generation and CO_2 emission with increased collection rate.

Amount of organic waste generated (tonnes/day)	Rate of collection (%)	Amount of organic waste collected for AD (tonnes/day)	Electricity generation (MWh/year)	CO_2 equiv. emission (kg)
326,22	60	195	7 676	9,61E+04
	75	244	9 600	1,20E+05

4.5.5 RDF Facility

RDF is produced to achieve the higher energy content fuels in different ways, which in general consist of source separation, mechanical separation, shredding, screening, drying, packing, palletizing and storing. The RDF contains high calorific values with higher energy yield. There are mainly two technologies to produce RDF from MSW. They are; Mechanical Biological Treatment (MBT) and Dry Stabilisation Process (Gendebien et.al., 2003). In this case study, we assume MBT process for the preparation of RDF. MBT is a waste management process which comprises of both mechanical and biological treatment process. The ferrous and non-ferrous metals are separated out using mechanical treatment process (i.e. magnetic separation for ferrous metals and eddy current separation for non-ferrous metals) and organic waste fraction are further screened out for stabilization. The heavy fractions are separated by air separation process. The schematic diagram illustrating MBT process is depicted in figure 21.

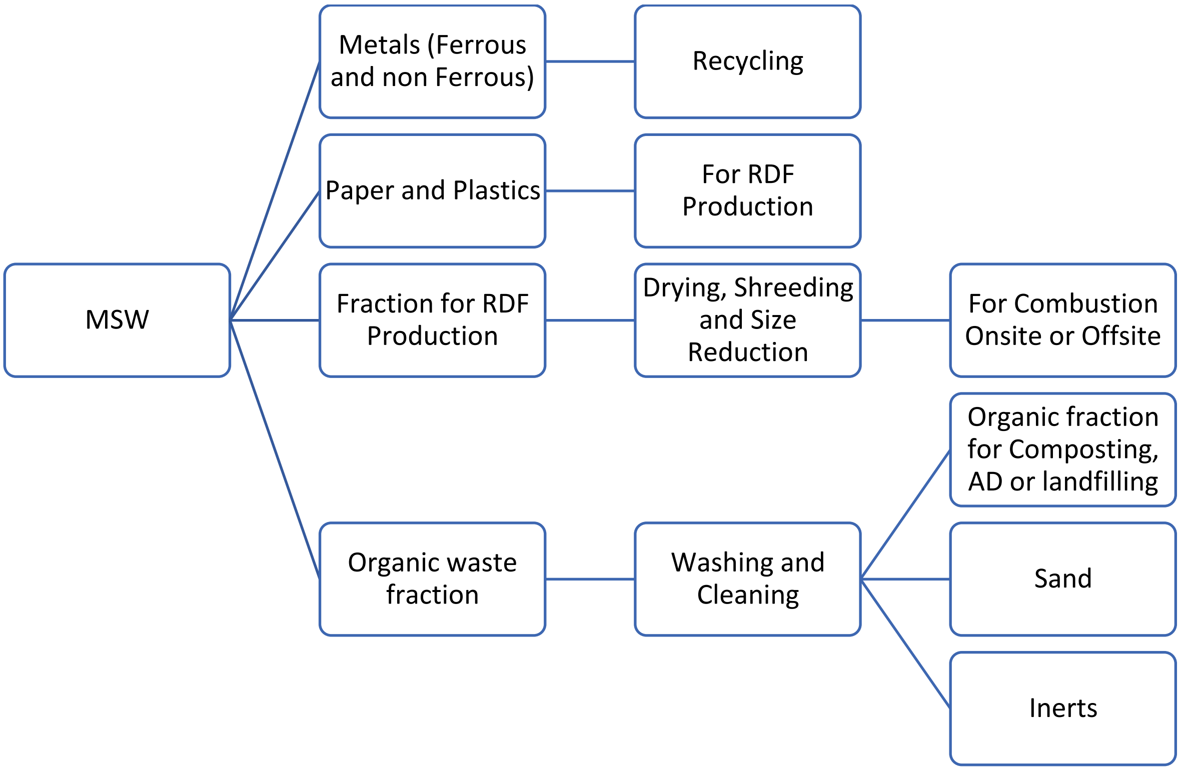

Figure 21: Schematic diagram of MBT process.

The mixed MSW after the source separation of organic waste fraction are taken to the MBT process to produce RDF. The total amount of mixed MSW taken to MBT process is about 110 000 tonnes per year. The organic rejects from the RDF production process is taken for landfilling, ferrous and non-ferrous metals is taken for recycling and other remaining rejects are taken for landfilling. The total amount of different waste fractions taken for RDF production process is depicted in table 13 below.

Table 13: Quantity of waste fractions taken to RDF production process.

MSW fractions	**Collected MSW fractions (t/a)**	**Share (%)**
Organic waste	49 890	45
Plastics	17 674	16
Paper	14 762	13
Glass	8 868	8
Metals	688	1
Textiles	3 765	3
Rubbers	1 963	2
Construction and demolition	7 365	7
Others	5097	5
Total	**110 072**	**100**

The recovery rate from various processes used for RDF production is calculated based on the approached adopted by Nasrullah et.al, 2014, 2015. The recovery rates for various equipment used is depicted in table 14 below.

Table 14:Recovery rate for different equipment used.

MSW fractions	Pre-screen	Metal	Eddy current	Air separation
Organic waste	48%	0%	0%	0%
Plastics	7%	1%	0%	1%
Paper	3%	0%	0%	0%
Glass	83%	0%	0%	0%
Metals	8%	56%	19%	13%
Textiles	4%	0%	0%	0%
Rubbers	5%	0%	0%	2%
Construction and demolition	28%	5%	1%	4%
Others	12%	0%	0%	0%

The total amount of RDF production is estimated about 72 700 tonnes per year which is 66% of the total MSW taken for the MBT process. The LHVar of RDF is calculated based on the approached employed by Nasrullah et.al, 2015 (i.e. 86% of the energy content of the MSW is contained by RDF). The LHVar of the mixed MSW after partial source separation of organic waste fraction is 5,11 MJ/kg and the estimated LHVar of RDF produced is about 6,65 MJ/kg. The amount of RDF produced from each waste fractions, their compositions and rejects from RDF production process is depicted in table 15 below.

Table 15: Amount of RDF produced, rejects and LHV.

MSW fractions	RDF (t/a)	RDF (%)
Organic waste	25 943	36
Plastics	16 110	22
Paper	14 319	20
Glass	1508	2
Metals	196	0
Textiles	3 614	5
Rubbers	1 828	3
Construction and demolition	4 788	7
Others	4 485	6
Total	**72 791**	**100**
Organic rejects (tonnes)	35 965	
Metal rejects (tonnes)	784	
Non-magnetic metal rejects (tonnes)	103	
Heavy fractions (tonnes)	429	
RDF LHVar (MJ/kg)	6,65	

The LHVar of RDF produced is low for the combustion process, so to obtain the minimum LHV of 7 MJ/kg the coal must be added to the system for co-incineration. About 1 245 tonnes of coal is added to the system for incineration annually. The electricity generation efficiency from RDF facility through co-combustion process is in the range of 25-35% (World energy.org, 2013). Here 30% of electricity generation efficiency is considered. Using equation 1 and 2 the total energy content and electricity generation is calculated. The total energy content by the RDF produced is about 134 400 MWh and for coal it is about 9 600 MWh. The total electricity generation capacity by the system is about 43 200 MWh annually.

Emission calculation from RDF facility

The calculation of CO_2 equiv. emission from RDF incineration is considered based on the biogenic and non-biogenic origin of the waste fraction incinerated. As suggested by the IPCC, 2006 the waste fractions with non-biogenic origin such as; plastic, rubber, textile and construction and demolition waste are taken into consideration for the calculation. The net emission of CO_2 is estimated based on the fossil carbon content by the emission material. Table 16 below depicts the fossil carbon content and biological carbon content of waste fraction taken to RDF facility.

Table 16: Total fossil carbon content in RDF waste fractions (Bjarnadóttir, et.al, 2002).

Waste fraction	Fossil Carbon (g C/kg waste)	Biological carbon (g C/kg waste)	Waste incinerated (tonnes)	Total fossil carbon (kg)
Plastics	590	0	16 110	9 504 739
Textile	278	278	3 614	1 004 803
Other combustible (Sum of rubber and construction and demolition waste)	400	93	6 615	2 646 138
Total			**26 339**	**13 155 680**

The total fossil carbon content in the incinerated RDF waste fraction is about 13 150 tonnes. According to Bjarnadóttir, et.al, 2002 there is 3,67 kg CO_2 emission from 1 kg of fossil carbon content. Using this information, the total CO_2 emission in a year is about 4,83E+07 kg and incinerating 1 kg of RDF will produce about 1,83 kg CO_2.

Using similar calculation method used in the section 4.5.2 the net GHGs emission from 1 245 tonnes of coal used annually is about 3,37E+06 kg CO_2 equiv.

Emission from RDF rejects

From RDF production process the end-product is RDF, organic rejects, metal rejects and heavy fraction rejects. The emission from the incinerated RDF produced is calculated in the earlier chapter. The organic rejects of about 35 900 tonnes annually is landfilled which results to the methane emission of about 1 142 tonnes annually. The calculation is like that in section 4.5.3. This results to the net GHGs emission of 2,85E+07 kg CO_2 equiv./a. The metal rejects of about 887 tonnes annually from the RDF production process is taken for recycling purpose which results to the net GHGs emission of about 4,44E+05 CO_2 equiv./a. It is assumed that the recycling of 1 tonnes of metal fraction produces 500 kg of CO_2 (Worldsteel.org, 2008). The heavy fractions produced from the RDF production process is landfilled.

4.5.6 Composting

Composting of organic MSW is done to prepare soil fertilizer and to decrease the volume of MSW that goes to the landfill sites. Composting of MSW is tremendously done in low-income countries, where there is an availability of high organic waste fractions. Preparation of compost reduces the greenhouse gas emission, generates money and benefits socially by reducing pollution. Composting generally consists of four steps, they are; collection, contaminant separation, size reduction and mixing and biological decomposition. A segregated separate collection system of organic waste fraction is done for preparing the compost. It is assumed that only about 45% of the total organic waste fraction generated is collected separately (Havukainen, Heikkinen and Horttanainen, 2016). It is estimated that only about 12-15% of organic MSW fraction is recovered as compost and rest of the organic MSW fraction is loss in terms of moisture and materials (Annepu, 2012). The estimation is based on the field visit done by Annepu and the team in the Indian cities where composting facility is installed. The schematic diagram illustrating the mass balance flowchart is depicted in figure 22. Using these data, the following table 17 is generated.

Table 17: Total compost recovered and rejects to landfill.

Yearly organic waste fractions generated (tonnes)	Yearly organic waste fractions collected (tonnes)	Compost recovery rate per tonnes	Compost recovered in a year (tonnes)	Total rejects in a year (tonnes)
119 070	53 580	13,5%	7 233	46 347

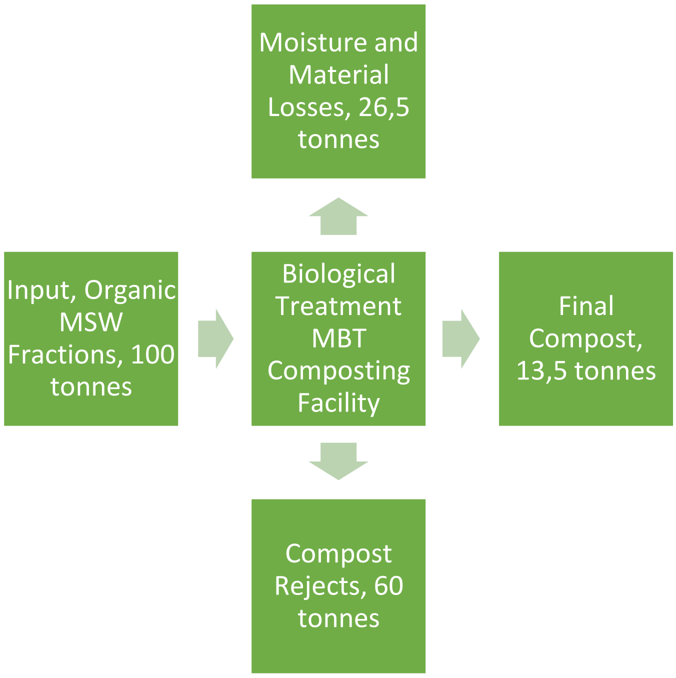

Figure 22: Mass balance flow chart of MBT composting facility (Source; Annepu, 2012)

Emission calculation from composting

Emission from composting process depends upon the type of waste fraction composted, temperature, supporting material used, moisture content and aeration facility. The composting process emits GHGs through operational activities and organic waste degradation process. The emission from operational activities such as transportation system is not included in this calculation. As suggested by the IPCC, 2006 the emission factor of CH_4 is 4 kg/ton of organic waste and 0.24 kg/ton of N_2O (Pipatti et al., 2006). Using these values, the annual emission of CH_4 is 214 320 kg and annual emission of N_2O is 12 860 kg. The net GHG_s emission annually is 9,19E+06 kg CO_2 – equiv./a.

4.5.7 Material Recovery Facility

The recyclable materials from the MSW composition are separated in the Material Recovery Facility (MRF). The MRF used here is different from that used in RDF production facility. The total collected MSW fraction is taken to the MRF, where separation of waste fractions occurs. The rate of recovery for different waste fractions depends on various equipment used during material recovery process. The metal scraps are separated using magnetic separation and eddy current separation while glass is separated using glass breaker screen. The separation efficiencies for different waste fractions using various equipment's is depicted in figure 23.

Waste Fraction	Trommel	Manual Sort/ Vacuum	Disc Screen 1	Disc Screen 2	Disc Screen 3	Glass Breaker Screen	Optical Glass	Optical PET	Optical HDPE	Magnet	Eddy Current Separator
Grass/Leaves	85										
Branches	10										
Food Waste	85										
Textiles	5										
Wood	5										
Rubber/Leather	5										
OCC			60	21	23						
Non-OCC Fiber				21	23						
Plastic Film	5	81									
HDPE									83		
PET								83			
Other Plastic	5										
Fe										88	
Al											87
Glass	10					87	88				
Other Inorganics	20										
Other Organics	80										

Figure 23: MRF separation efficiencies for mixed MSW (N. Pressley et al., 2015).

Those recyclable materials are further used as a raw material for making the new product. The recycled materials used reduces the energy consumption and the amount of total emission in the atmosphere compared to that of virgin materials. In this case study, metal and glass fractions are recycled to produce the new material. According to the Enviros Consulting Ltd, 2003 the net GHG_s emission from glass recycling is 529 kg/tonnes of CO_2

equiv. throughout its life cycle while the net emission from the virgin material used to produce glass is 843 kg/tonnes of CO_2 equiv. This reduces the emission by 37%.

The emission from recycling facility to make 1 ton of iron is 500 kg of CO_2 equiv. while to make 1 ton of iron from the virgin material is 2.1 ton of CO_2 equiv. (Worldsteel.org, 2008). This reduces the emission of by 76%.

Using these data on separation efficiency and emission from recycling process, the table 18 below is created.

Table 18: Emission from metal and glass recycling.

Waste fractions	Collected amount of waste fractions (tonnes/year)	Separation efficiency (%)	Total amount of waste produced from MRF (tonnes/year)	Emission factor for recycling (kg/tonnes of CO_2)	Total emission from recycling (kg CO_2 equiv.)	Emission reduction when replacing virgin materials (kg CO_2 equiv.)
Metals	688,29	87	598	500	299 000	956 800
Glass	8868,49	87	7715	529	4 081 235	2 422 510
Total					4 380 235	3 379 310

The total GHGs emission from the recycling process of the waste fraction is 4,38E+06 kg CO_2 equiv. annually.

4.5.8 Landfilling

Landfilling is the least preferred option for waste management. Those waste which cannot be reused, recycled or used for energy recovery is disposed to the landfill. However, in most of the developing countries, where there is no proper waste management system the collected waste is disposed of to the landfill. The air pollutants emitted from the landfill is a source of GHGs. The methane emission calculation from the landfill is calculated based on DM recommended by IPCC, 1996. DOC is the significant parameter affecting the generation of CH_4 which varies for different waste fractions. The accurate DOC can be estimated by sampling waste fractions at disposal sites. As sampling of waste fractions is not carried out in this thesis work, available default value of DOC suggested by IPCC, 2006 is used here. The default value on DOC content in percentage of wet waste is depicted in figure 24. Using the information given in section 4.5.3 and using equation 6 with different DOC for different waste fractions the net CH_4 generation from landfilling of collected waste is 5141 t/a and GHGs emission is 1,29E+08 kg CO_2 – equiv./a.

TABLE 2.4
DEFAULT DRY MATTER CONTENT, DOC CONTENT, TOTAL CARBON CONTENT AND FOSSIL CARBON FRACTION OF DIFFERENT MSW COMPONENTS

MSW component	Dry matter content in % of wet weight [1]	DOC content in % of wet waste		DOC content in % of dry waste		Total carbon content in % of dry weight		Fossil carbon fraction in % of total carbon	
	Default	Default	Range	Default	Range [2]	Default	Range	Default	Range
Paper/cardboard	90	40	36 - 45	44	40 - 50	46	42 - 50	1	0 - 5
Textiles [3]	80	24	20 - 40	30	25 - 50	50	25 - 50	20	0 - 50
Food waste	40	15	8 - 20	38	20 - 50	38	20 - 50	-	-
Wood	85 [4]	43	39 - 46	50	46 - 54	50	46 - 54	-	-
Garden and Park waste	40	20	18 - 22	49	45 - 55	49	45 - 55	0	0
Nappies	40	24	18 - 32	60	44 - 80	70	54 - 90	10	10
Rubber and Leather	84	(39) [5]	(39) [5]	(47) [5]	(47) [5]	67	67	20	20
Plastics	100	-	-	-	-	75	67 - 85	100	95 - 100
Metal [6]	100	-	-	-	-	NA	NA	NA	NA
Glass [6]	100	-	-	-	-	NA	NA	NA	NA
Other, inert waste	90	-	-	-	-	3	0 - 5	100	50 - 100

[1] The moisture content given here applies to the specific waste types before they enter the collection and treatment. In samples taken from collected waste or from e.g., SWDS the moisture content of each waste type will vary by moisture of co-existing waste and weather during handling.

[2] The range refers to the minimum and maximum data reported by Dehoust *et al.*, 2002; Gangdonggu, 1997; Guendehou, 2004; JESC, 2001; Jager and Blok, 1993; Würdinger *et al.*, 1997; and Zeschmar-Lahl, 2002.

[3] 40 percent of textile are assumed to be synthetic (default). Expert judgement by the authors.

[4] This value is for wood products at the end of life. Typical dry matter content of wood at the time of harvest (that is for garden and park waste) is 40 percent. Expert judgement by the authors.

[5] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al., 1985; Rose and Steinbüchel, 2005).

[6] Metal and glass contain some carbon of fossil origin. Combustion of significant amounts of glass or metal is not common.

Figure 24: Default values for DOC in different waste types (Pipatti et al., 2006).

The net GHGs emission from each fraction of landfilled waste is depicted in table 19 below.

Table 19: Net GHGs emission from landfilling.

Waste Components	Share (%)	DOC content in % of wet waste	CH_4 emission (t/a)	GHGs emission ($kg\ CO2 -$ equiv./a
Organic Waste	63,22	15	3290	8,22E+07
Plastics	10,8	-	-	-
Paper	9,02	40	1498	3,75E+07
Glass	5,42	-	-	-
Metals	0,42	-	-	-
Textiles	2,3	24	191	4,79E+06
Rubbers	1,2	39	162	4,06E+06
Construction and demolition	4,5	-	-	-
Others	1,2	-	-	-
Total			**5141**	**1,29E+08**

4.6 WtE Scenarios

For the case study of energy generation and GHGs emission from waste fractions in KMC five different scenarios are formed. The first scenario is business as usual scenario where collected waste fractions are landfilled in the Sisdol landfill site. It is estimated about 163 655 tonnes of MSW fractions is collected annually with a collection efficiency of 86,9%. The other four scenarios comprise of combination of composting, RDF incineration, landfilling, material recovery, AD, and mass incineration. The detail description on scenarios is discussed below. Table 20 below depicts various scenarios and waste fractions taken to different waste management options.

Table 20: Different waste to energy scenarios.

Composition	Organic waste	Plastic	Paper	Const. & demolition	Textiles	Rubber	Metal	Glass	Others
Scenario 1	Landfill								
Scenario 2	Mass incineration								
Scenario 3	Landfill gas recovery	Landfill	Landfill gas recovery	Landfill	Landfill gas recovery	Landfill gas recovery	Landfill	Landfill	Landfill
Scenario 4	Composting + RDF incineration	RDF incineration							
Scenario 5	Anaerobic digestion + landfill	Landfill	Landfill	Landfill	Landfill	Landfill	Material recovery	Material recovery	Landfill

Scenario 1 (Landfill)

The scenario 1 is the business as usual scenario where collected amount of waste fraction is disposed to the Sisdol landfill site. Out of 516 tonnes of MSW generated daily in KMC, 448 tonnes of waste are collected and disposed. The collection efficiency of the waste fraction is assumed to be 86.9%. The scenario 1 is the present situation of KMC where no waste to energy facilities are under operation.

Scenario 2 (Mass incineration)

The scenario 2 consist of a mass incineration process. The total collected MSW is taken for mass incineration process where there is addition of coal to the system to obtain an LHV of 7 MJ/kg. The amount of electricity generated and GHGs emission annually is calculated in this scenario based on the waste management options.

Scenario 3 (Landfill gas recovery)

The scenario 3 compromise of landfill gas recovery option where collected amount of MSW fractions is taken to landfill disposal site for methane gas collection. The methane gas generated from MSW fraction is recovered in this scenario. The landfill gas collection rate is assumed to be 60%. The waste fractions with DOC content is responsible for the generation of methane gas while other waste fractions without DOC content is not taken into consideration for methane generation calculation.

Scenario 4 (Composting + RDF incineration)

The scenario 4 comprises of composting facility and RDF incineration. The organic waste fractions collected separately is used for composting and all other mixed MSW fractions are taken for RDF production process. The RDF produced from the process is co-incinerated with coal. The organic rejects from the RDF production process is landfilled and the metal rejects is taken for recycling purpose. The heavy fractions from the RDF production process is also landfilled.

Scenario 5 (AD + Material Recovery + Landfill)

In scenario 5 the separately collected organic waste fraction is taken for AD process. The metal and glass waste fractions are taken for material recovery facility and the remaining organic waste fractions along with other waste fractions is taken for landfilling.

5. RESULTS AND DISCUSSIONS

Based on the available data's on MSW generation and collection various equations and assumptions were made to calculate the electricity generation and GHGs emissions annually. Five different scenarios were formed, and the result is discussed in this chapter. Table 21 below depicts different waste management options, electricity generation, and GHGs emission associated with it. The mass balance of MSW fractions in different scenarios is depicted in table 22 below.

Scenario 1 is the business as usual scenario where there is no production of electricity and the total collected waste is disposed of to the Sisdol landfill site. Scenario 1 generates the highest quantity of GHGs emission i.e. 1,29E+08 kg CO_2 annually. Scenario 2 is the second highest generator of GHGs, which accounts for about 1,01E+08 kg CO_2 equiv. The emission is higher compared to other energy recovery options due to use of coal for electricity generation. The net GHGs emission annually from MSW only in mass incineration is about 3,84E+07 kg CO_2 – equiv. and from coal it is about 6,22E+07 kg CO_2 – equiv. In Scenario 4 the total GHGs emission is from co-incineration of RDF and coal, landfilling of organic rejects, metal recycling and composting. The net GHGs emission from RDF incineration is about 4,83E+07 kg CO_2 – equiv., from coal it 3,37E+06 kg CO_2 – equiv., from organic rejects it is 2,85E+07 kg CO_2 – equiv., from metal recycling it is 4,44E+05 kg CO_2 – equiv., and from composting it is 9,19E+06 kg CO_2 – equiv. The total GHGs emission in scenario 4 is about 8,98E+07 kg CO_2 – equiv. In Scenario 5 the total GHGs emission occurs from AD, material recovery and landfilling of the remaining MSW fraction. The 45% of the total generated organic waste fraction is taken for AD process. The 49 890 t/a organic waste fraction along with other collected waste fractions except glass and metal is taken for landfilling. The emission from the landfilling is calculated like that in section 4.5.8. The total GHGs emission from Scenario 5 is 9,04E+07 kg CO_2 – equiv. Compared to the Scenario 1 or present scenario the emission level can be reduced by about 30% in Scenario 4 and 5, 64% in Scenario 3, and 22% in Scenario 2. The Scenario 3 is the best suitable scenario in terms of reducing the total GHGs emission. The emission is due to the methane slip that occurs during the combustion process. Figure 25 below depicts the relative difference in emission reduction compared to the scenario 1. The result shows that it is possible to reduce GHGs emission by about 82 000 tonnes annually by implementing Scenario 3.

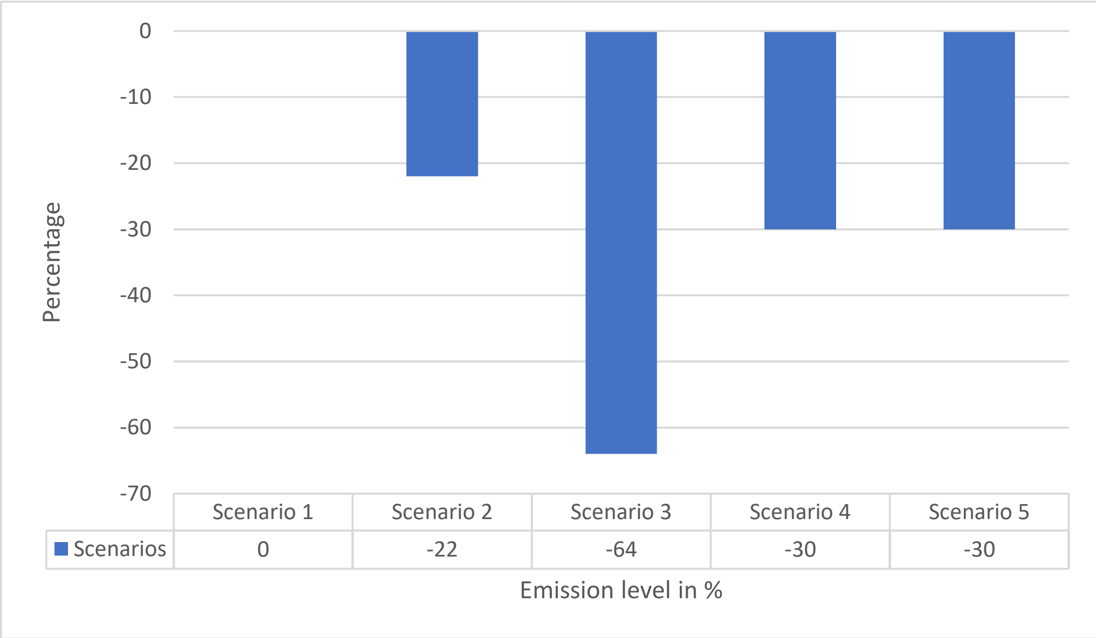

Figure 25: Annual emission level compared to Scenario 1.

The highest amount of electricity generation is in scenario 2 where production is made through mass incineration. However, the system is not fully renewable due to use of coal as an external source to obtain the net calorific value of 7 MJ/kg. The estimated electricity generation annually by only MSW fractions during mass incineration is about 38 800 MWh and by coal it is 37 500 MWh. The estimated average LHV of MSW fractions in KMC is 4,07 MJ/kg which is technically not feasible for mass incineration. In Scenario 3 the total amount of electricity generation through landfill gas recovery option is about 12 800 MWh. The electricity generation in Scenario 4 is from co-incineration of RDF and small amount of additional coal. The total amount of electricity generation capacity is about 43 200 MWh. In Scenario 5 the electricity is generated through AD process. The annual electricity generation is about 5 740 MWh. The organic waste fractions of KMC accounts for about 63% and is best suitable for electricity generation through landfill gas recovery and AD process.

Table 21: Electricity generation and GHGs emission in various scenarios annually.

Electricity generation annually (MWh)					
Waste management options	Scenarios				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Mass incineration	-	76 300	-	-	-
RDF incineration	-	-	-	43 200	-
AD	-	-	-	-	5 740
Landfill gas recovery	-	-	12 853	-	-
Total		**76 300**	**12 853**	**43 200**	**5 740**
GHGs emission annually (kg CO_2 equiv.)					
Waste management options	Scenarios				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Landfill	1,29E+08	-	-	-	8,60E+07
Mass incineration	-	1,01E+08	-	-	
RDF incineration + Organic rejects + Metal recycling	-	-	-	8,06E+07	-
AD	-	-	-	-	7,19E+04
Composting	-	-	-	9,19E+06	-
Landfill gas recovery	-	-	4,63E+07		-
Material recovery		-	-	-	4,38E+06
Total	**1,29E+08**	**1,01E+08**	**4,63E+07**	**8,98E+07**	**9,04E+07**

Table 22: Mass balance of waste fraction in different scenario

Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
Total collected waste to landfill (t/a)	163 655	Total collected waste to mass incineration (t/a)	163 655	Total collected waste to landfill recovery option (t/a)	163 655	Organic waste to composting (t/a)	53 582	Organic waste to AD (t/a)	53 582
Waste not collected (t/a)	24 671	Waste not collected (t/a)	24 671	Waste not collected (t/a)	24 671	Waste to RDF preparation (t/a)	110 073	Waste to material recycling (t/a)	9 556
Total generated waste (t/a)	**188 325**	**Total generated waste (t/a)**	**188 325**	**Total generated waste (t/a)**	**188 325**	Not collected (t/a)	24 671	Waste to landfilling (t/a)	100 517
						Total generated waste (t/a)	**188 325**	Not collected (t/a)	24 671
								Total generated waste (t/a)	**188 325**

6. POLICY RECOMMENDATIONS AND CONCLUSION

The waste management system in KMC at present is focused on waste collection and disposal. No waste segregation at a source or at collection point is carried out. The segregation of recyclable waste fractions such as; metals, plastic bottles, papers and cardboards are carried out by scavengers. Disposal of the waste fraction to Sisdol landfill site is running out of capacity and frequent demonstration from local people around landfill site has led to the closure and open situation. To implement the Integrated Solid Waste Management System (ISWMS) in KMC some reforms and policy implementation must be carried out which are discussed below in this chapter.

6.1 Recommendations

The present waste management system in KMC must be improved to achieve the goal of ISWMS. The waste management rules and regulation must be strongly implemented, and more budget must be allocated for recovery options. Cooperation between private and public sector is necessary performing their own assigned task. Making the concerned authority to follow the rules and regulation on waste management precisely is the most important task to overcome the problem of waste management in KMC. The local bodies such as; municipalities and VDCs much act actively and relevantly on MSW management to proceed towards cleaner and healthy environment along with the generation of electricity.

6.1.1 Advancement of Reduce, Reuse and Recycle

The waste fraction of KMC is highly organic which constitute about 63% of total waste fractions. The segregation of waste fraction at source level and composting organic waste can be a suitable option for reducing the waste fraction going for landfill disposal. It also reduces the amount of GHGs emission. The establishment of composting plant at a local level can be made. Collection of recyclable materials at a source or at collection point must be carried out.

6.1.2 Strong Implementation of Waste Policy and Regulations

KMC has formulated major policies and legislation for the proper and effective management of MSW. However, those major policies seem being not implemented effectively. The implementation of such existing policies as discussed in section 3.2 is necessary for smooth and effective management of solid waste. The local and executive bodies responsible for waste management must implement them adequately.

6.1.3 Change in Present Waste Management System

At present the MSW fractions are collected from open piles on the roadside, riversides and open spaces. This trend of collecting habit must be stopped. The container must be provided to the communities, schools, hospitals, and institution for the collection of waste with the facility of source separation. The waste fractions are a valuable source and must be used for recovery purpose. Landfilling must be taken as a least preferred option.

6.1.4 Public-Private Participation (PPP)

KMC participates with a private organization for the collection and disposal of MSW in Kathmandu. But the smooth functioning and good cooperation between them are not seen. For the betterment of waste management, a competitive participation between private and public sector is essential.

6.1.5 Polluter Pays

According to the Solid Waste Management Act, 2011 the local bodies can charge a fee for the collection, transportation, recovery, and disposal of solid waste in Nepal. The initiation of polluter pays principle in KMC can be made which will encourage public to decrease the amount of waste generated and it also leads to the effective management of waste fractions. At present, the private organization involved in the waste management collects fees in some part of KMC but is not effective throughout KMC.

6.1.6 Effective Allocation of Budget

The budget allocated for the management of MSW in KMC is extensively distributed for the collection and street sweeping. The money for disposal of waste fractions is less and there is no money allocated for recovery purpose. During the preparation of this thesis work, it is found that not all sum of money is spent during a fiscal year. It is necessary to re-allocate the budget and make an effective expenditure.

6.1.7 Research and Development

The SWMTSC of Nepal is responsible for all kind of technical research related to waste. It is necessary to invest and carry out more research work, collect data, and update them timely. Most often the data available are not reliable and sufficient which leads to the incomplete findings.

6.2 Conclusions

The MSW fractions of KMC has a greater potential for generating electricity. The generated electricity can be an addition to the national grid and the system of generating electricity can reduce GHGs by about 64% compared to the present scenario. The 82 000 tonnes of CO_2 can be reduced annually compared to the emission at present situation if WtE option is implemented. The MSW fractions of KMC is highly organic, which is best suitable for generating electricity through landfill gas recovery or AD process. The amount of electricity generated from organic waste fractions is higher in landfill gas recovery option than that of AD process. It is because in landfill gas recovery option the total collected organic waste fraction is utilized while in AD process only 45% of the separately collected organic waste fractions is used. The improvement in the collection rate of organic waste fractions can increase the amount of electricity generation in AD process.

As the solid waste fractions of KMC is highly organic the mass incineration process is not technically feasible for generating electricity. The organic waste fractions can be either composted, landfilled with landfill gas recovery option or anaerobically digested producing biogas. Although composting is not an option for electricity generation, it reduces the amount of GHGs emission and can be a source of fertilizer.

KMC started, SWM facility since 1980s. Although it has a long history of waste management, no significant improvement has been made. KMC is focused on waste collection and disposal which do not reduces the amount of emission. KMC must change its present waste management system to improve the environment and human health. The waste collecting, transporting, and disposing habit must be improved. More focus must be made on recovery options and landfilling must be regarded as the last option. Construction of new landfill site must be made fast as Sisdol landfill site is on the verge of running out of the capacity.

REFERENCES

Adb.org. (2013). Solid Waste Management in Nepal Current Status and Policy Recommendations. [online] Available at: https://www.adb.org/sites/default/files/publication/30366/solid-waste-management-nepal.pdf [Accessed 5 Dec. 2017].

Adb.org. (n.d.). [online] Available at: https://www.adb.org/sites/default/files/project-document/63293/40124-reg-spr-09.pdf [Accessed 14 Nov. 2017].

Adhikari Subedi, S. (2015). Domestic Biogas Production and Use in Nepal- A Simple, Reliable, Clean and Cost-Effective Solution to Provide Energy Security to the Rural Households. [online] Mro.massey.ac.nz. Available at: https://mro.massey.ac.nz/bitstream/handle/10179/8274/02_whole.pdf?sequence=2&isAllowed=y [Accessed 1 Apr. 2018].

Adhikari, B., Khanal, S. and Miyan, R. (2015). Quantitative Study of Biogas Generation Potential from Different Landfill Sites of Nepal. [online] Research gate. Available at: https://www.researchgate.net/publication/271589394_Quantitative_Study_of_Biogas_Generation_Potential_from_Different_Landfill_Sites_of_Nepal [Accessed 15 Jan. 2018].

Aepc.gov.np. (n.d.). Year-Wise Installation of Biogas Plants (1992/93 to 2015/16). [online] Available at: http://www.aepc.gov.np/?option=statistics&page=substatistics&mid=6&sub_id=49&id=4 [Accessed 25 Dec. 2017].

Alam, R., Chowdhury, M., Hasan, G., Karanjit, B. and Shrestha, L. (2006). Generation, storage, collection and transportation of municipal solid waste – A case study in the city of Kathmandu, capital of Nepal. [online] Sciencedirect.com. Available at: http://www.sciencedirect.com/science/article/pii/S0956053X07001067?via%3Dihub [Accessed 18 Dec. 2017].

Annepu, R. (2012). Sustainable Solid Waste Management in India. [online] Seas.columbia.edu. Available at: http://www.seas.columbia.edu/earth/wtert/sofos/Sustainable%20Solid%20Waste%20Management%20in%20India_Final.pdf [Accessed 13 Feb. 2018].

Apo-tokyo.org. (2007). Solid Waste Management: Issues and Challenges in Asia. [online] Available at: http://www.apo-tokyo.org/00e-books/IS-22_SolidWasteMgt/IS-22_SolidWasteMgt.pdf [Accessed 5 Dec. 2017].

Araldsen, T. (2016). Biogas in Nepal: Limitations for the Expansion of Community Plants. [online] Brage.bibsys.no. Available at: https://brage.bibsys.no/xmlui/bitstream/handle/11250/2422464/Araldsen%2C%20TPRL.pdf?sequence=1 [Accessed 5 Dec. 2017].

BIOGAS CALCULATION TOOL USER´S GUIDE. (2014). [ebook] AEPC, p.8. Available at: https://www.google.com.np/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwje_dCw3tvYAhWFJ5QKHTkiDTwQFgglMAA&url=http%3A%2F%2Fw2ebazaar.org.np%2Fdownload%2F4&usg=AOvVaw1PeRYQ1cLrnz2ofI0RMpy8 [Accessed 12 Jan. 2018].

Bjarnadóttir, H., Friðriksson. G., Johnsen. T., and Sletsen. H., (2002). Guidelines for the use of LCA in the waste management sector. [online] Available at: https://www.researchgate.net/publication/252870130_Guidelines_for_the_use_of_LCA_in_the_waste_management_sector. [Accessed 10 Mar. 2018].

CBS, 2014. Population monograph of Nepal. [online] Available at: http://cbs.gov.np/image/data/Population/Population%20Monograph%20of%20Nepal%202014/Population%20Monograph%20V03.pdf [Accessed 26 Nov. 2017].

Cbs.gov.np. (2013). STATISTICAL YEAR BOOK OF NEPAL - 2013. [online] Available at: http://cbs.gov.np/image/data/Publication/Statistical%20Year%20book%202013_SS/Statistical-Year-book-2013_SS.pdf [Accessed 10 Dec. 2017].

Cbs.gov.np. (2016). Nepal in Figures 2016. [online] Available at: http://cbs.gov.np/image/data/2017/Nepal%20in%20Figures%202016.pdf [Accessed 6 Apr. 2018].

Chandler, A., Kosson, D., Eighmy, T., Hartlen, J., van der Sloot, H., Hjelmar, O. and Vehlow, J. (1997). Municipal solid waste incinerator residues. Amsterdam: Elsevier, pp.59-62.

Cheremisinoff, N. (2007). Handbook of solid waste management and waste minimization technologies. Norwich, NY: Knovel.

Czajczyńska, D., Anguilano, L., Ghazal, H., Krzyżyńska, R., Reynolds, A., Spencer, N. and Jouhara, H. (2017). Potential of pyrolysis processes in the waste management sector. [online] ScienceDirect. Available at: http://www.sciencedirect.com/science/article/pii/S2451904917300690#s0005 [Accessed 22 Nov. 2017].

Dong, T. and Lee, B. (2009). Analysis of potential RDF resources from solid waste and their energy values in the largest industrial city of Korea. [online] ScienceDirect. Available at: https://www.sciencedirect.com/science/article/pii/S0956053X0800408X [Accessed 12 Jan. 2018].

Engineeringtoolbox.com. (n.d.). Fuels - Higher and Lower Calorific Values. [online] Available at: https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html [Accessed 15 Feb. 2018].

Environment.org.np. (2004). A DIAGNOSTIC REPORT ON STATE OF SOLID WASTE MANAGEMENT IN MUNICIPALITIES OF NEPAL. [online] Available at: http://environment.org.np/wp-content/uploads/2011/01/Diagnostic_report_on_the_state_of_SWM_in_Nepal.pdf [Accessed 19 Dec. 2017].

Epa.gov. (2011). Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills. [online] Available at: https://www.epa.gov/sites/production/files/2015-12/documents/landfills.pdf [Accessed 5 Jan. 2018].

Extwprlegs1.fao.org. (2011). Solid Waste Management Act, 2068 (2011). [online] Available at: http://extwprlegs1.fao.org/docs/pdf/nep137767.pdf [Accessed 2 Dec. 2017].

Gasification-syngas.org. (n.d.). Gasification The waste to energy solution. [online] Available at: http://www.gasification-syngas.org/uploads/downloads/GTC_Waste_to_Energy.pdf [Accessed 21 Nov. 2017].

Gamse. T., and Meidiana. C. (2010). Development of Waste Management Practices in Indonesia. [online] Available at: http://www.academia.edu/9665177/Development_of_Waste_Management_Practices_in_Indonesia. [Accessed 3 Dec. 2017].

Gendebien, A., Leavens, A., Blackmore, K., Godley, A., Lewin, K., Whiting, K., Davis, R., Giegrich, J., Fehrenbach, H., Gromke, U., del Bufalo, N. and Hogg, D. (2003). REFUSE DERIVED FUEL, CURRENT PRACTICE AND PERSPECTIVES (B4-3040/2000/306517/MAR/E3). [online] Ec.europa.eu. Available at: http://ec.europa.eu/environment/waste/studies/pdf/rdf.pdf [Accessed 3 Mar. 2018].

Globalmethane.org. (2016). Overview of Anaerobic Digestion for Municipal Solid Waste. [online] Available at: https://www.globalmethane.org/documents/AD-Training-Presentation_Oct2016.pdf [Accessed 25 Nov. 2017].

Havukainen, J., Heikkinen, S. and Horttanainen, M. (2016). Possibilities to improve the share of material recovery of municipal solid waste in Finland. [online] Available at: http://www.doria.fi/bitstream/handle/10024/123014/Havukainen+et+al.+2016+Material+recovery+of+MSW+in+Finland.pdf?sequence=2 [Accessed 14 Apr. 2018].

Honda, H. (2005). Life cycle GHG emission analysis of power generation systems: Japanese case. [online] Univie.ac.at. Available at: http://www.univie.ac.at/photovoltaik/umwelt/LCA_japanstudy.pdf [Accessed 25 Apr. 2018].

Islam, N., (2016). Municipal Solid Waste to Energy Generation in Bangladesh: Possible Scenarios to Generate Renewable Electricity in Dhaka and Chittagong City. [online] Available at: https://www.hindawi.com/journals/jre/2016/1712370/#B62 [Accessed 01 Dec. 2018].

ISWA. (n.d.). Solid waste management. [online]Available at: http://www.iswa.org/index.php?eID=tx_iswaknowledgebase_download&documentUid=4944 [Accessed 15 Nov. 2017].

Jensen, J. and Pipatti, R. (n.d.). CH4 EMISSIONS FROM SOLID WASTE DISPOSAL. [online] Ipcc-nggip.iges.or.jp. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_1_CH4_Solid_Waste.pdf [Accessed 7 Jan. 2018].

Lawcommission.gov.np. (1987). Solid Waste (Management and Resource Mobilization) Act, 2044 (1987). [online] Available at: http://www.lawcommission.gov.np/en/documents/2015/08/solid-waste-management-and-resource-mobilization-act-2044-1987.pdf [Accessed 29 Nov. 2017].

Liebetrau, J., Reinelt, T., Agostini, A. and Linke, B. (2017). Methane emissions from biogas plants. [online] Ieabioenergy.com. Available at: http://www.ieabioenergy.com/wp-content/uploads/2018/01/Methane-Emission_web_end_small.pdf [Accessed 25 Apr. 2018].

Nasrullah M, e. (2015). Mass, energy and material balances of SRF production process. Part 3: solid recovered fuel produced from municipal solid waste. - PubMed - NCBI. [online] Ncbi.nlm.nih.gov. Available at: https://www.ncbi.nlm.nih.gov/pubmed/25568089 [Accessed 10 Apr. 2018].

Nasrullah M, e. (2014). Mass, energy and material balances of SRF production process. Part 2: SRF produced from construction and demolition waste. [online] Available at: https://www.ncbi.nlm.nih.gov/pubmed/25074716

N. Pressley, P., Levis, J., Damgaard, A., Barlaz, M. and DeCarolis, J. (2015). Analysis of material recovery facility for use in life-cycle assessment. [online] Sciencedirect. Available at: https://www.sciencedirect.com/science/article/pii/S0956053X14004346?via%3Dihub#s0125 [Accessed 13 Apr. 2018].

Nayono, S. (2009). Anaerobic Digestion of Organic Solid Waste for Energy Production. [online] Google Books. Available at: https://books.google.com.np/books?hl=en&lr=&id=cyZAAbGI6X0C&oi=fnd&pg=PR3&dq=Anaerobic+digestion+of+organic+solid+waste+for+energy+production&ots=MBruRFArYL&sig=sJMtaER6dJy-AbWfpx7WVn1PIIU&redir_esc=y#v=onepage&q&f=false [Accessed 10 Jan. 2018].

Oagnep.gov.np. (2015). Solid Waste Management of Kathmandu Metropolitan City Environment Audit Report, 2015. [online] Available at: http://www.oagnep.gov.np/downloadfile/Enviroment%20Audit%202071_1434876762.pdf [Accessed 13 Dec. 2017].

Open_jicareport.jica.go.jp. (2005). THE STUDY ON THE SOLID WASTE MANAGEMENT FOR THE KATHMANDU VALLEY. [online] Available at: http://open_jicareport.jica.go.jp/pdf/11808631_01.pdf [Accessed 23 Dec. 2017].

Open_jicareport.jica.go.jp. (n.d.). Environmental Monitoring at Sisdol Landfill SiteThe Study on the Solid Waste Management. [online] Available at: http://open_jicareport.jica.go.jp/pdf/11808664_09.pdf [Accessed 21 Dec. 2017].

Packagingfedn.co.uk. (2003). Glass Recycling - Life Cycle Carbon Dioxide Emissions. [online] Available at: http://www.packagingfedn.co.uk/images/reports/Enviros_Report.pdf [Accessed 3 Feb. 2018].

Pandey, R. (n.d.). Solid Waste Management Practice and Health Implication: A Case of Kathmandu Metropolitan City, Nepal. [online] Nepjol.info. Available at: https://www.nepjol.info/index.php/HR/article/view/2419/2159 [Accessed 15 Dec. 2017].
Pathak (2017). Solid waste management baseline study of 60 new municipalities. [online] Researchgate. Available at: https://www.researchgate.net/publication/313161363_Solid_Waste_Management_Baseline_Study_of_60_New_Municipalities [Accessed 28 Nov. 2017].

Pathak, (2013). Recycled Materials from Solid Waste Stream in Kathmandu Valley: Recovery and Economic values. [online] Available at: https://www.researchgate.net/profile/DR_Pathak/project/Recycled-Materials-from-Solid-Waste-Stream-in-Kathmandu-Valley-Recovery-and-Economic-values/attachment/589197e5934940fcce417eee/AS:456865420189697@1485936612998/download/Resources+recovery+from+municipal+solid+waste+in+Kathmandu+Valley.pdf?context=ProjectUpdatesLog [Accessed 12 Apr. 2018].

Pipatti, R., Yamada, M., Sharma, C., Scheehle, E., Silva Alves, J., Gao, Q., Cabrera, C., Mareckova, K., Oonk, H., Smith, A. and Svardal, P. (2006). BIOLOGICAL TREATMENT OF SOLID WASTE. [online] Ipcc-nggip.iges.or.jp. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf [Accessed 21 Feb. 2018].

Pipatti, R., Yamada, M., Sharma, C., Scheehle, E., Silva Alves, J., Gao, Q., Cabrera, C., Mareckova, K., Oonk, H., Smith, A. and Svardal, P. (2006). WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA. [online] Ipcc-nggip.iges.or.jp. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf [Accessed 8 Apr. 2018].

Pokhrel, D. and Viraraghavan, T. (2005). Municipal solid waste management in Nepal: Practices and challenges. [online] Researchgate. Available at:

https://www.researchgate.net/publication/7815758_Municipal_solid_waste_management_in_Nepal_Practices_and_challenges [Accessed 26 Nov. 2017].

Ranabhat, R. (2015). Life Cycle Assessment of Municipal Solid Waste Management System in Kathmandu, Nepal. [online] Nepjol.info. Available at: https://www.nepjol.info/index.php/JACEM/article/download/14926/12133 [Accessed 17 Dec. 2017].

Rand, T., Haukohl, J. and Marxen, U. (2000). Municipal Solid Waste Incineration Requirements for a Successful Project. [online] Documents.worldbank.org. Available at: http://documents.worldbank.org/curated/en/886281468740211060/pdf/multi-page.pdf [Accessed 4 Dec. 2017].

Sacep.org. (2001). State of the Environment, Nepal. [online] Available at: http://www.sacep.org/pdf/Reports-Technical/2001-State-of-Environment-Report-Nepal.pdf [Accessed 3 Jan. 2018].

Scarlat, N., Motola, V., Dallemand, J., Monforti-Ferrario, F. and Mofor, L. (2015). Evaluation of energy potential of Municipal Solid Waste from African urban areas. [online] ScienceDirect. Available at: https://www.sciencedirect.com/science/article/pii/S1364032115005389 [Accessed 9 Jan. 2018].

Singh, R., Yabar, H., Mizunoya, T., Higano, Y. and Rakwal, R. (2014). Potential Benefits of Introducing Integrated Solid Waste Management Approach in Developing Countries: A Case Study in Kathmandu City. [online] ccsenet.org. Available at: http://www.ccsenet.org/journal/index.php/jsd/article/view/40131 [Accessed 14 Dec. 2017].

Srisaeng, N., Tippayawong, N. and Tippayawong, K. (2017). Energetic and Economic Feasibility of RDF to Energy Plant for a Local Thai Municipality. [online] ScienceDirect. Available at: https://www.sciencedirect.com/science/article/pii/S1876610217301455 [Accessed 11 Jan. 2018].

Swmtsc.gov.np. (1996). Solid Waste Management National Policy 2053 (1996). [online] Available at: http://swmtsc.gov.np/upload/attachment/20.pdf [Accessed 31 Nov. 2017].

Unep.or.jp. (2009). Policy and Regulations – Madhyapur Thimi Municipality. [online] Available at: http://www.unep.or.jp/ietc/spc/activities/GPWM/data/T2/AB_2_P_PolicyAndRegulations_Nepal.pdf [Accessed 1 Dec. 2017].

Web.mit.edu. (1999). Municipal Solid Waste Incineration. [online] Available at: http://web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/MunicipalSWIncin.pdf [Accessed 5 Jan. 2018].

World Bank. (2013). Managing Nepal's Urban Transition. [online] Available at: http://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition [Accessed 12 Dec. 2017].

Worldbank.org. (2012). WHAT A WASTE A Global Review of Solid Waste Management. [online] Available at: http://documents.worldbank.org/curated/en/302341468126264791/pdf/68135-REVISED-What-a-Waste-2012-Final-updated.pdf [Accessed 15 Nov. 2017].

Worldenergy.org. (2016). World Energy Resources Waste to Energy | 2016. [online] Available at: https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf [Accessed 15 Jan. 2018].

Worldsteel.org. (2008). 2008 Sustainability Report of the world steel industry. [online] Available at: https://www.worldsteel.org/en/dam/jcr:e6f75b6a-5c2a-4690-94f8-72f82bb674a0/2008.pdf [Accessed 9 Feb. 2018].

Zafar, S. (2016). Waste to Energy Conversion Routes. [online] BioEnergy Consult. Available at: https://www.bioenergyconsult.com/waste-to-energy-pathways/ [Accessed 21 Mar. 2018].

Appendix 1

Household waste composition in 58 municipalities (%)

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Amargadhi	71.50	9.13	11.88	1.35	0.21	3.79	1.04	1.09
2	Baglung	40.44	24.18	15.83	8.19	2.36	3.92	2.80	2.28
3	Banepa	68.11	11.19	9.14	1.33	1.83	1.19	0.32	6.90
4	Bhadrapur	72.99	11.58	8.04	0.00	0.00	6.27	0.62	0.50
5	Bhaktapur	77.48	8.52	6.79	0.55	0.79	0.69	0.00	5.19
6	Bharatpur	78.96	4.63	7.84	3.08	1.74	2.32	1.00	0.43
7	Bhimdatta	48.17	8.16	5.99	4.92	1.13	2.30	0.00	29.32
8	Bhimeshwor	56.68	5.56	8.63	0.00	0.00	0.00	2.58	26.55
9	Bidur	70.19	12.04	7.21	3.70	0.15	5.62	0.00	1.09
10	Biratnagar SMPC	85.77	5.05	5.18	1.03	0.22	1.00	0.43	1.32
11	Birendranagar	73.95	11.06	10.15	0.94	1.08	0.76	0.06	2.00
12	Birgunj SMPC	58.48	13.70	7.44	9.99	1.06	0.00	0.00	9.32
13	Butwal	74.60	8.82	5.73	1.99	1.57	1.57	1.42	4.30
14	Byas	70.87	10.89	7.97	2.92	0.59	2.06	1.05	3.66
15	Damak	63.40	5.35	6.51	0.66	1.06	2.12	1.23	19.67
16	Dasharathchanda	35.64	8.19	34.17	2.51	1.41	4.19	1.18	12.70
17	Dhangadhi	68.13	13.11	10.07	2.67	1.08	0.00	2.30	2.65
18	Dhankuta	59.61	17.86	11.90	0.00	1.28	3.05	0.25	6.04
19	Dharan	58.34	15.49	11.30	2.43	6.24	2.96	0.75	2.48
20	Dhulikhel	52.61	17.65	7.11	11.10	0.53	3.88	0.46	6.68
21	Dipayal Silgadhi	43.64	15.14	9.49	19.02	3.83	5.66	2.69	0.52
22	Gaur	76.78	2.51	2.29	0.30	0.31	0.69	0.00	17.12
23	Ghorahi	80.63	8.34	5.44	0.78	0.00	0.63	2.50	1.68
24	Gorkha	48.16	12.33	20.43	2.69	0.83	0.49	0.00	15.06
25	Gulariya	56.33	9.46	5.48	1.18	7.91	0.00	2.08	17.55
26	Hetauda	50.93	18.92	18.39	2.15	0.17	2.79	0.86	5.79
27	Ilam	57.98	9.18	14.22	4.51	3.84	2.38	4.10	3.78
28	Inaruwa	56.27	5.79	6.54	1.28	0.13	0.20	0.26	29.54
29	Itahari	61.23	12.56	19.35	1.49	0.00	2.05	0.00	3.32
30	Jaleshwor	70.13	17.11	9.05	0.00	0.00	1.12	2.59	0.00
31	Janakpur	71.53	17.23	10.51	0.00	0.41	0.00	0.32	0.00
32	Kalaiya	66.60	4.36	5.38	0.93	0.49	3.14	0.41	18.69

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
33	Kamalamai	62.72	11.17	7.88	3.04	2.61	1.84	1.73	9.00
34	Kapilvastu	81.72	8.52	6.36	0.48	0.36	2.56	0.00	0.00
35	Kathmandu MPC	64.24	15.96	8.66	3.75	1.72	3.40	1.12	1.15
36	Khandbari	46.82	14.76	13.33	4.90	4.94	6.85	0.40	8.00
37	Kirtipur	74.34	15.06	8.01	0.62	0.23	1.47	0.27	0.00
38	Lahan	84.52	7.93	5.61	0.10	1.04	0.00	0.65	0.14
39	Lalitpur SMPC	77.94	9.81	5.23	1.99	0.66	0.74	0.75	2.86
40	Lekhnath	59.80	9.12	10.63	10.13	1.73	0.00	0.00	8.59
41	Madhyapur Thimi	48.86	12.78	9.83	1.98	0.03	0.00	1.74	24.78
42	Malangawa	60.45	6.63	5.63	4.44	2.61	4.64	2.14	13.46
43	Mechinagar	70.19	12.87	11.93	0.92	1.73	0.00	0.86	1.50
44	Narayan	84.62	6.95	5.83	0.00	0.71	0.76	1.13	0.00
45	Nepalgunj	76.27	12.75	6.94	0.09	0.84	1.91	0.52	0.67
46	Panauti	82.95	7.82	5.06	0.00	0.00	1.78	0.47	1.93
47	Pokhara SMPC	62.65	8.80	11.61	4.54	5.74	2.21	2.82	1.63
48	Putalibazar	71.84	8.69	3.86	11.82	0.00	0.23	0.00	3.57
49	Rajbiraj	80.04	8.02	3.93	1.27	0.95	2.40	0.11	3.29
50	Ramgram	51.06	7.83	15.34	0.10	0.28	3.33	0.52	21.54
51	Ratnanagar	74.00	20.00	2.00	1.00	0.67	1.00	0.33	1.00
52	Siddharthanagar	64.15	16.54	15.22	2.09	1.99	0.00	0.00	0.00
53	Siraha	67.78	3.58	6.01	0.34	1.59	1.48	4.31	14.91
54	Tansen	44.18	10.25	10.11	6.40	5.06	3.86	3.63	16.52
55	Tikapur	61.77	9.10	12.87	3.64	6.26	6.36	0.00	0.00
56	Triyuga	55.55	4.75	18.25	0.50	3.81	2.75	2.13	12.26
57	Tulsipur	85.87	4.77	6.38	2.65	0.33	0.00	0.00	0.00
58	Waling	47.24	11.28	10.53	5.14	2.61	4.33	0.00	18.87
Average composition		66.37	11.97	8.95	3.07	1.88	2.22	1.07	4.48

Source: Adb.org,2013

Appendix 2

Commercial waste composition in 58 municipalities (%)

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Amargadhi	35.13	19.28	27.43	15.11	2.92	0.03	0.12	0.00
2	Baglung	41.14	14.96	26.91	13.67	1.37	0.38	0.53	1.04
3	Banepa	41.28	17.47	23.89	8.08	2.62	0.00	0.81	5.86
4	Bhadrapur	24.35	61.71	11.99	0.00	0.00	0.00	0.00	1.95
5	Bhaktapur	38.73	21.29	18.03	2.14	6.20	0.73	0.37	12.51
6	Bharatpur	56.76	8.73	23.70	6.46	0.95	3.09	0.00	0.32
7	Bhimdatta	34.41	21.71	19.46	2.26	1.51	7.31	0.89	12.45
8	Bhimeshwor	25.04	35.20	16.66	5.79	0.00	0.21	0.00	17.12
9	Bidur	53.03	22.43	17.02	5.73	0.77	0.98	0.05	0.00
10	Biratnagar SMPC	58.53	18.86	19.11	0.00	0.00	0.00	2.18	1.32
11	Birendranagar	25.07	6.01	9.98	39.59	0.58	9.30	7.71	1.77
12	Birgunj SMPC	34.65	19.15	31.77	8.81	2.58	0.00	0.00	3.04
13	Butwal	41.08	20.77	19.67	6.67	1.60	0.00	0.00	10.21
14	Byas	47.24	15.85	21.56	5.98	3.19	3.43	1.19	1.55
15	Damak	52.04	11.34	17.48	0.64	6.44	0.35	3.02	8.70
16	Dasharathchanda	24.04	16.56	35.37	1.23	6.84	3.51	2.71	9.75
17	Dhangadhi	22.78	27.50	12.15	14.71	4.70	3.10	5.56	9.50
18	Dhankuta	37.93	17.42	21.07	0.00	4.16	8.15	0.00	11.28
19	Dharan	25.57	18.27	17.09	7.99	6.76	4.23	0.00	20.09
20	Dhulikhel	67.18	14.36	7.18	8.24	0.00	0.00	0.00	3.04
21	Dipayal Silgadhi	27.95	32.41	17.25	17.47	2.05	0.00	2.87	0.00
22	Gaur	46.32	9.68	15.44	0.00	0.00	0.00	0.00	28.57
23	Ghorahi	40.49	22.51	21.44	6.64	2.56	0.00	1.44	4.92
24	Gorkha	51.46	26.69	13.50	0.00	3.95	0.00	0.00	4.40
25	Gulariya	18.08	37.19	29.70	2.52	0.47	0.00	0.56	11.50
26	Hetuda	31.64	28.30	18.44	6.15	6.05	0.83	0.00	8.59
27	Ilam	56.13	14.04	11.73	2.41	5.05	3.04	4.11	3.50
28	Inaruwa	45.37	9.02	13.26	0.00	1.09	0.00	0.00	31.27
29	Itahari	23.13	36.17	30.41	0.53	2.52	2.63	0.00	4.61
30	Jaleshwor	38.23	51.00	7.85	0.00	0.00	0.00	2.92	0.00
31	Janakpur	38.62	22.82	28.38	0.00	0.00	0.61	1.52	8.06
32	Kalaiya	44.07	23.69	20.41	0.00	2.26	0.00	0.00	9.57
33	Kamalamai	37.54	17.04	29.36	7.07	1.02	0.00	0.00	7.96

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
34	Kapilvastu	46.04	24.28	21.34	0.00	0.00	0.00	8.34	0.00
35	Kathmandu MPC	45.44	24.29	23.29	2.86	2.65	1.03	0.00	0.45
36	Khandbari	29.20	20.89	32.31	5.36	4.07	3.29	0.19	4.69
37	Kirtipur	65.77	25.99	5.45	2.79	0.00	0.00	0.00	0.00
38	Lahan	42.46	33.41	14.96	0.72	4.98	0.00	0.00	3.48
39	Lalitpur SMPC	39.36	21.05	30.14	1.01	0.25	0.06	0.16	7.97
40	Lekhnath	33.59	19.50	32.45	6.05	0.98	0.00	0.00	7.43
41	Madhyapur Thimi	22.05	28.04	25.37	1.12	0.00	0.00	0.17	23.26
42	Malangawa	23.91	17.72	28.16	7.67	1.56	9.57	6.94	4.47
43	Mechinagar	32.91	24.65	31.85	1.33	4.08	0.00	1.26	3.93
44	Narayan	44.93	16.84	33.06	1.82	3.36	0.00	0.00	0.00
45	Nepalgunj	54.96	13.67	16.34	11.23	3.49	0.31	0.00	0.00
46	Panauti	36.09	47.55	14.16	0.91	0.00	1.30	0.00	0.00
47	Pokhara SMPC	47.23	12.60	24.68	6.14	1.44	6.95	0.13	0.84
48	Putalibazar	23.87	28.42	24.10	0.00	0.00	0.00	0.00	23.62
49	Rajbiraj	46.42	12.94	23.50	0.85	3.08	1.03	0.61	11.58
50	Ramgram	43.12	21.83	22.31	0.00	1.18	5.33	0.00	6.23
51	Ratnanagar	38.12	22.96	26.24	4.30	2.70	2.43	1.29	1.96
52	Sidharthanagar	37.44	47.14	15.13	0.00	0.30	0.00	0.00	0.00
53	Siraha	48.36	7.64	27.99	7.35	1.97	0.44	2.14	4.11
54	Tansen	46.49	10.80	24.53	3.36	1.57	0.20	0.29	12.76
55	Tikapur	28.40	18.44	33.05	5.58	9.27	5.27	0.00	0.00
56	Triyuga	51.93	13.90	17.49	1.49	0.00	6.13	0.00	9.08
57	Tulsipur	38.47	17.01	13.64	14.32	9.47	0.08	1.46	5.55
58	Waling	51.04	12.00	15.59	9.64	1.39	1.95	0.00	8.40
Average composition		43.24	22.09	22.76	3.88	2.30	1.51	0.50	3.72

Source; Adb.org,2013

Appendix 3

Institutional waste composition in 58 municipalities (%)

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Amargadhi	13.36	13.14	63.74	1.12	5.68	0.98	1.06	0.92
2	Baglung	25.70	22.67	46.96	0.41	0.99	0.34	0.04	2.90
3	Banepa	15.13	31.17	42.75	2.47	3.90	0.24	4.33	0.00
4	Bhadrapur	16.52	5.72	77.76	0.00	0.00	0.00	0.00	0.00
5	Bhaktapur	30.35	18.77	29.35	2.95	3.15	3.46	1.68	10.29
6	Bharatpur	30.84	18.89	49.37	0.00	0.38	0.00	0.30	0.22
7	Bhimdatta	24.30	12.05	32.63	0.42	0.41	0.92	1.19	28.08
8	Bhimeshwor	11.74	4.97	46.21	0.00	0.12	0.12	0.00	36.83
9	Bidur	15.17	24.54	55.53	0.00	1.49	1.49	1.79	0.00
10	Biratnagar SMPC	41.56	19.48	35.49	0.00	1.54	0.39	0.00	1.54
11	Birendranagar	24.62	21.84	51.41	1.78	0.03	0.20	0.00	0.12
12	Birgunj SMPC	16.99	21.54	50.18	0.00	0.00	0.00	0.00	11.29
13	Butwal	24.48	17.32	29.55	0.00	0.35	2.36	2.58	23.37
14	Byas	42.11	21.02	29.90	1.63	0.69	0.72	0.61	3.33
15	Damak	38.04	12.16	20.95	0.02	8.00	1.66	0.61	18.56
16	Dasharathchanda	10.20	11.16	36.31	7.97	12.71	5.44	5.01	11.21
17	Dhangadhi	16.36	17.59	50.89	0.73	1.99	0.27	0.00	12.17
18	Dhankuta	16.90	20.80	40.25	0.00	0.46	0.00	0.46	21.12
19	Dharan	22.39	21.29	37.81	3.70	3.89	2.26	1.18	7.47
20	Dhulikhel	36.25	15.22	48.53	0.00	0.00	0.00	0.00	0.00
21	Dipayal Silgadhi	18.30	27.93	34.71	3.88	1.21	0.92	1.61	11.43
22	Gaur	22.42	6.59	21.87	4.44	0.00	0.00	0.00	44.68
23	Ghorahi	21.38	17.32	39.33	2.50	0.43	3.67	0.39	14.98
24	Gorkha	18.03	26.47	45.55	1.82	2.50	0.00	0.00	5.64
25	Gulariya	8.95	11.28	56.74	0.08	0.00	0.00	0.62	22.33
26	Hetuda	8.01	29.61	49.09	0.98	1.33	1.30	0.08	9.61
27	Ilam	60.10	6.83	16.34	1.96	0.97	0.88	0.82	12.10
28	Inaruwa	1.50	4.00	40.80	0.00	0.59	0.88	0.00	52.23
29	Itahari	25.64	24.90	40.13	2.95	0.00	0.00	0.00	6.38
30	Jaleshwor	17.09	35.70	46.44	0.77	0.00	0.00	0.00	0.00
31	Janakpur	11.23	25.58	43.38	0.00	0.00	0.00	0.00	19.81
32	Kalaiya	9.98	11.24	36.08	0.00	7.51	1.39	0.47	33.33
33	Kamalamai	12.28	17.48	50.12	4.54	1.93	0.00	1.74	11.91

	Municipality	Organic Waste	Plastics	Paper and Paper Products	Glass	Metals	Textiles	Rubber and Leather	Others
34	Kapilvastu	0.00	16.63	83.37	0.00	0.00	0.00	0.00	0.00
35	Kathmandu MPC	20.29	24.55	44.28	1.37	1.13	3.89	1.14	3.35
36	Khandbari	4.94	22.70	58.79	0.91	1.18	3.18	0.99	7.31
37	Kirtipur	22.13	14.31	59.55	3.25	0.00	0.77	0.00	0.00
38	Lahan	27.95	14.30	50.87	0.01	1.17	0.00	0.52	5.19
39	Lalitpur SMPC	14.53	23.05	41.05	0.11	1.43	0.00	0.19	19.64
40	Lekhnath	11.19	11.51	48.58	6.17	1.92	0.00	2.39	18.24
41	Madhyapur Thimi	0.77	19.18	60.20	0.10	0.00	0.00	0.83	18.92
42	Malangawa	5.85	21.57	28.23	5.70	0.73	4.78	0.00	33.14
43	Mechinagar	24.74	15.32	44.62	5.65	0.00	0.00	3.89	5.78
44	Narayan	16.56	29.03	54.41	0.00	0.00	0.00	0.00	0.00
45	Nepalgunj	39.30	13.02	44.24	0.00	1.92	0.00	0.00	1.53
46	Panauti	33.67	16.54	44.43	0.07	0.00	3.01	0.65	1.63
47	Pokhara SMPC	26.19	8.14	65.35	0.00	0.00	0.00	0.00	0.32
48	Putalibazar	1.63	33.64	53.04	0.00	0.00	0.00	0.00	11.69
49	Rajbiraj	12.32	10.51	40.09	1.13	0.51	1.03	0.12	34.30
50	Ramgram	19.84	7.28	31.47	10.62	1.44	0.06	0.38	28.92
51	Ratnanagar	10.26	18.94	60.31	0.20	0.62	0.21	0.93	8.53
52	Sidharthanagar	1.08	23.21	75.71	0.00	0.00	0.00	0.00	0.00
53	Siraha	29.10	4.17	43.19	0.27	2.57	1.56	2.66	16.49
54	Tansen	22.92	11.25	24.05	5.16	1.91	4.02	3.75	26.94
55	Tikapur	27.92	19.16	47.00	0.00	4.60	0.00	0.00	1.32
56	Triyuga	10.89	14.34	67.24	0.00	3.21	1.46	0.45	2.41
57	Tulsipur	2.94	20.53	56.97	0.00	2.31	0.00	0.00	17.26
58	Waling	41.57	10.99	17.08	2.12	1.91	0.92	0.36	25.06
Average composition		21.73	20.76	44.53	1.17	1.22	2.07	0.82	7.71

Source; Adb.org,2013

Appendix 4

Household waste composition in 60 new municipalities

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Abukhaireni	81.60	7.16	4.01	3.53	1.45	0.00	0.34	1.92
2	Api	70.02	12.02	9.14	8.43	0.00	0.39	0.00	0.00
3	Atariya	61.67	11.68	12.16	0.64	3.35	1.88	0.57	8.04
5	Badimalika	61.72	5.46	2.67	7.21	3.44	2.37	13.44	3.69
6	Bagchaur	53.07	10.78	7.80	0.55	0.35	0.00	0.07	27.39
7	Bandipur	76.51	6.74	3.23	5.24	2.72	0.00	1.99	3.56
4	Banganga	76.38	11.41	8.46	1.68	0.65	0.67	0.75	0.00
8	Bansgadi	60.61	8.41	11.88	3.69	4.75	0.00	3.20	7.46
9	Bardibas	63.34	10.75	14.53	4.65	0.27	1.38	0.00	5.09
10	Belauri	81.15	12.97	4.06	1.81	0.00	0.00	0.00	0.00
11	Belbari	68.79	16.95	7.04	1.84	0.00	4.63	0.75	0.00
12	Beni	43.73	12.47	14.22	8.65	6.72	5.01	4.38	4.82
13	Beshishahar	76.48	17.52	6.01	0.00	0.00	0.00	0.00	0.00
14	Bhajani - Trishakti	59.51	6.93	4.58	1.71	0.08	0.25	0.00	26.94
15	Bheriganga	75.35	5.86	3.59	2.64	1.25	0.41	0.00	10.92
16	Bhojpur	69.55	7.32	4.75	9.42	2.02	1.93	0.34	4.67
17	Birtamod	82.17	11.43	5.23	0.39	0.17	0.45	0.00	0.16
18	Chandrapur	65.14	8.62	7.89	5.59	0.54	1.49	0.00	10.72
19	Chautara	47.34	12.65	13.99	9.89	6.59	3.05	0.28	6.20
20	Devdaha	75.33	15.20	7.88	0.24	1.24	0.11	0.00	0.00
21	Duhabi - Bhulahi	76.07	7.12	4.31	0.24	0.13	0.79	0.00	11.34
22	Dullu	66.47	10.88	4.40	0.00	0.85	0.90	0.00	16.50
24	Gaindakot	81.33	6.10	6.96	3.44	1.06	0.96	0.15	0.00
23	Ganeshman - Charnath	51.09	12.52	8.68	15.12	0.67	3.65	0.89	7.37
25	Ghodaghodi	65.69	8.04	7.04	0.00	0.00	0.49	0.00	18.74
26	Golbazar	83.26	5.64	2.90	3.32	1.63	1.79	1.45	0.00
27	Ishworpur	66.03	4.84	4.96	5.68	0.00	0.00	0.00	18.49
28	Jayaprithibi	61.82	9.49	14.23	4.74	0.00	6.17	2.77	0.79
29	Kamalbazar	81.40	5.33	4.60	0.00	0.00	4.00	0.00	4.67
30	Kanchanrup	70.96	8.37	5.65	3.05	0.15	0.82	0.00	11.00
31	Kankai	61.50	10.59	17.91	2.81	0.98	2.72	0.20	3.28
32	Katari	53.93	11.70	9.24	1.10	0.98	3.27	0.98	18.80
33	Kohalbi	83.07	5.59	6.92	1.32	0.88	1.26	0.30	0.66
34	Kushma	56.57	6.74	23.60	2.20	4.88	0.00	0.00	6.01
35	Lamahi	81.52	3.30	3.95	0.71	0.54	1.36	0.18	8.44

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
36	Lamkichuwa	80.27	5.47	5.16	0.74	3.93	2.55	0.00	1.88
37	Liwang	42.73	12.86	11.59	13.10	1.23	4.68	3.79	10.02
38	Madyabindhu	60.91	22.06	10.42	2.20	1.22	0.00	0.00	3.18
39	Mangalsen	78.52	9.51	6.20	4.50	0.42	0.85	0.00	0.00
40	Manthali	38.02	8.30	12.54	33.02	3.63	0.43	3.45	0.61
41	Mirchaiya	38.02	13.68	13.72	10.29	4.38	6.95	2.56	10.40
42	Mushikot	72.39	5.56	7.05	5.43	2.75	4.62	2.18	0.00
43	Nijgadh	79.20	14.79	1.67	2.20	0.33	0.79	0.81	0.20
44	Pakhribas	45.34	10.80	11.11	18.69	2.19	2.74	2.16	6.96
45	Palungtar	67.41	12.58	6.88	4.89	2.73	2.81	0.00	2.71
47	Parshuram	59.67	6.78	10.13	2.96	0.37	2.56	2.74	14.78
46	Patan	53.19	12.64	18.72	3.32	0.00	4.83	0.00	7.29
48	Pyuthan	63.53	10.66	7.97	2.52	3.28	4.13	2.26	5.64
49	Rajapur	76.89	20.13	1.26	0.90	0.00	0.80	0.00	0.03
50	Ramechap	53.63	5.79	7.95	0.31	2.19	0.34	0.12	29.68
51	Rangeli	42.31	9.66	7.94	2.32	2.06	8.80	0.40	26.50
52	Rapti	70.13	8.57	5.93	5.88	1.32	2.87	0.68	4.61
53	Resunga	81.03	8.76	5.11	0.00	0.00	0.28	0.00	4.83
54	Sainamaina	81.77	7.48	3.00	4.60	0.86	0.00	0.00	2.28
55	Sanoshree-Taratal	50.21	17.77	23.09	5.11	0.43	3.40	0.00	0.00
56	Sanphebazar	71.81	16.51	9.03	0.80	0.86	0.00	0.00	1.00
57	Shani Arjun	70.77	4.68	10.47	3.44	0.13	0.00	2.78	7.73
58	Sharada	68.02	16.38	3.95	3.46	0.96	3.94	0.34	2.96
59	Shivraj	65.59	18.78	5.92	3.63	0.09	0.31	0.28	5.41
60	Suvaghat	73.53	19.81	6.66	0.00	0.00	0.00	0.00	0.00
Weighted average		**67.89**	**10.43**	**7.86**	**4.04**	**1.37**	**1.71**	**0.77**	**5.93**

Source; Pathak, 2017

Appendix 5

Institutional waste composition in 60 new municipalities

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Abukhaireni	51.30	13.72	30.01	0.00	0.00	3.55	1.42	0.00
2	Api	57.01	16.27	26.72	0.00	0.00	0.00	0.00	0.00
3	Atariya	14.84	25.32	44.59	0.75	0.00	0.53	0.00	13.97
5	Badimalika	1.51	15.94	48.23	15.85	0.00	1.63	2.60	14.25
6	Bagchaur	37.55	13.80	38.41	0.00	0.00	0.00	0.00	10.23
7	Bandipur	25.69	25.40	48.91	0.00	0.00	0.00	0.00	0.00
4	Banganga	26.89	23.89	35.47	3.80	1.27	0.47	0.00	8.20
8	Bansgadi	27.84	16.49	39.41	3.26	0.95	0.00	3.33	8.70
9	Bardibas	31.66	20.19	38.17	3.67	1.42	0.00	0.00	4.89
10	Belauri	30.37	33.58	34.87	1.19	0.00	0.00	0.00	0.00
11	Belbari	19.06	29.67	28.43	0.74	0.00	0.71	0.00	21.39
12	Beni	16.84	27.22	27.85	5.41	8.39	0.00	4.20	10.09
13	Beshishahar	13.45	43.80	42.75	0.00	0.00	0.00	0.00	0.00
14	Bhajani - Trishakti	15.26	13.34	37.62	0.00	0.00	0.00	0.00	33.79
15	Bheriganga	12.38	20.03	41.83	0.00	0.00	0.00	0.96	24.81
16	Bhojpur	9.62	36.94	25.28	0.67	2.25	0.79	2.67	21.78
17	Birtamod	51.73	27.43	17.48	3.20	0.00	0.00	0.00	0.16
18	Chandrapur	47.48	8.09	36.86	0.00	0.00	0.64	0.00	6.93
19	Chautara	36.39	32.38	26.89	0.00	0.00	0.21	0.00	4.14
20	Devdaha	28.53	32.80	38.67	0.00	0.00	0.00	0.00	0.00
21	Duhabi - Bhulahi	10.19	24.37	51.97	0.57	0.00	0.00	0.00	12.90
22	Dullu	10.52	20.03	69.45	0.00	0.00	0.00	0.00	0.00
24	Gaindakot	6.86	26.37	34.45	0.00	0.00	0.00	1.46	30.87
23	Ganeshman - Charnath	52.18	16.38	28.52	0.00	0.29	0.00	1.04	1.59
25	Ghodaghodi	17.06	24.19	37.61	0.00	0.31	0.26	0.00	20.57
26	Golbazar	7.07	21.74	56.97	1.13	6.90	0.00	6.19	0.00
27	Ishworpur	0.00	26.88	64.21	0.00	0.00	5.35	0.00	3.56
28	Jayaprithibi	23.38	17.23	59.08	0.00	0.00	0.00	0.31	0.00
29	Kamalbazar	18.70	3.49	70.06	0.16	0.00	0.00	0.00	7.59
30	Kanchanrup	16.40	16.74	44.53	0.77	0.89	0.54	0.00	20.12
31	Kankai	18.04	9.70	65.48	0.00	0.04	0.00	0.58	6.16
32	Katari	2.07	20.46	51.18	0.22	0.00	1.26	0.00	24.81
33	Kohalbi	41.82	11.96	26.91	0.00	0.00	0.74	0.26	18.31
34	Kushma	13.68	29.28	46.20	0.00	0.00	0.00	0.00	10.84
35	Lamahi	19.49	16.67	53.42	0.00	0.00	2.08	0.00	8.33
36	Lamkichuwa	13.54	22.47	47.46	0.59	1.29	1.73	0.00	12.92

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
37	Liwang	9.01	18.55	48.59	0.00	1.66	2.49	1.47	18.22
38	Madyabindhu	19.66	48.81	31.53	0.00	0.00	0.00	0.00	0.00
39	Mangalsen	27.90	20.80	48.94	0.00	0.00	0.00	2.36	0.00
40	Manthali	14.40	27.33	38.07	0.00	7.52	3.84	3.01	5.83
41	Mirchaiya	37.22	14.36	23.08	7.38	3.90	2.08	2.24	9.72
42	Mushikot	10.44	22.10	56.79	1.36	4.48	2.85	1.98	0.00
43	Nijgadh	8.56	41.58	49.20	0.00	0.00	0.66	0.00	0.00
44	Pakhribas	24.03	11.44	46.77	1.91	0.00	8.46	0.00	7.39
45	Palungtar	47.28	20.41	24.88	0.00	0.00	0.00	0.00	7.42
47	Parshuram	0.00	24.48	75.52	0.00	0.00	0.00	0.00	0.00
46	Patan	6.55	14.97	33.06	21.15	0.25	0.00	0.00	24.02
48	Pyuthan	19.64	16.44	33.85	1.52	1.60	2.59	2.73	21.62
49	Rajapur	17.25	24.67	27.39	7.24	0.00	0.00	0.00	23.45
50	Ramechap	4.91	12.69	42.55	0.00	0.52	0.48	0.17	38.68
51	Rangeli	4.62	15.15	59.51	0.00	0.00	0.00	0.00	20.72
52	Rapti	21.30	26.10	49.74	1.56	0.00	0.00	0.00	1.30
53	Resunga	19.87	18.89	20.61	0.00	0.00	0.11	0.00	40.52
54	Sainamaina	8.81	20.77	25.87	40.27	0.00	0.00	0.00	4.29
55	Sanoshree-Taratal	8.99	25.11	44.30	0.00	0.00	0.00	0.00	21.60
56	Sanphebazar	0.00	55.00	40.00	0.00	0.00	5.00	0.00	0.00
57	Shani Arjun	4.82	62.14	19.79	0.00	0.00	0.00	0.00	13.25
58	Sharada	4.32	12.92	82.56	0.00	0.00	0.00	0.00	0.19
59	Shivraj	14.42	40.45	37.05	0.00	0.00	1.96	0.33	5.78
60	Suvaghat	40.66	48.51	10.82	0.00	0.00	0.00	0.00	0.00
	Average	**20.98**	**22.84**	**41.01**	**2.00**	**1.07**	**0.81**	**1.04**	**10.24**

Source; Pathak, 2017

Appendix 6

Commercial waste composition in 60 new municipalities

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
1	Abukhaireni	37.62	17.68	16.59	3.55	24.55	0.00	0.00	0.00
2	Api	64.61	8.15	17.28	8.55	0.00	0.00	1.40	0.00
3	Atariya	37.00	21.57	20.52	10.89	1.05	0.65	0.00	8.32
5	Badimalika	52.74	4.57	13.53	14.96	0.21	5.71	0.00	8.29
6	Bagchaur	60.13	9.78	6.03	22.13	1.51	0.00	0.00	0.42
7	Bandipur	73.22	13.99	7.91	4.87	0.00	0.00	0.00	0.00
4	Banganga	46.54	8.39	8.52	35.22	1.14	0.00	0.01	0.17
8	Bansgadi	39.06	11.98	19.13	4.65	7.67	0.00	2.58	14.93
9	Bardibas	54.45	13.27	19.69	7.65	0.00	3.51	0.00	1.43
10	Belauri	61.48	8.94	27.39	2.19	0.00	0.00	0.00	0.00
11	Belbari	55.24	21.15	14.75	0.00	2.12	0.00	0.00	6.73
12	Beni	51.70	22.70	18.11	0.00	1.08	0.64	0.59	5.18
13	Beshishahar	34.88	17.32	35.81	10.58	1.41	0.00	0.00	0.00
14	Bhajani - Trishakti	49.90	18.43	7.75	6.86	0.00	1.67	0.00	15.39
15	Bheriganga	61.95	9.67	12.40	2.16	0.43	0.00	0.97	12.43
16	Bhojpur	34.93	20.92	32.79	2.65	5.89	0.77	0.00	2.05
17	Birtamod	48.57	18.96	11.30	21.17	0.00	0.00	0.00	0.00
18	Chandrapur	52.75	9.43	7.41	28.10	2.31	0.00	0.00	0.00
19	Chautara	50.37	9.14	21.46	15.05	1.06	0.00	0.00	2.92
20	Devdaha	29.76	17.13	12.53	38.51	2.07	0.00	0.00	0.00
21	Duhabi - Bhulahi	29.19	26.29	34.65	0.00	0.00	2.69	0.00	7.18
22	Dullu	32.20	31.36	28.81	0.00	7.63	0.00	0.00	0.00
24	Gaindakot	44.47	24.34	14.13	6.86	2.95	0.98	0.00	6.26
23	Ganeshman - Charnath	58.41	18.53	13.10	5.20	2.50	1.09	0.00	1.18
25	Ghodaghodi	76.02	10.42	4.63	0.15	0.00	1.13	0.00	7.65
26	Golbazar	59.66	2.33	7.21	26.07	0.13	0.14	4.46	0.00
27	Ishworpur	84.64	3.58	2.28	5.90	0.49	0.92	1.81	0.38
28	Jayaprithibi	36.36	12.12	13.13	30.30	0.00	5.05	3.03	0.00
29	Kamalbazar	82.95	7.25	4.41	4.90	0.00	0.00	0.00	0.49
30	Kanchanrup	72.52	13.44	4.92	0.59	2.02	0.00	0.00	6.51
31	Kankai	57.49	12.93	14.93	1.68	0.78	2.29	0.00	9.88
32	Katari	18.20	19.23	5.52	47.17	1.04	0.33	0.15	8.37
33	Kohalbi	40.72	24.47	23.52	0.00	0.74	9.49	0.00	1.05
34	Kushma	57.01	15.50	10.65	5.47	2.04	3.36	1.14	4.82
35	Lamahi	51.89	6.90	6.20	19.03	8.83	0.00	1.03	6.12
36	Lamkichuwa	45.67	21.03	4.28	18.61	9.16	0.00	0.00	1.25

S.N.	Name of Municipality	Organic waste	Plastics	Paper/Paper products	Glass	Metals	Textiles	Rubber and Leather	Others
37	Liwang	44.49	11.82	11.55	25.55	4.01	0.00	0.00	2.58
38	Madyabindhu	74.85	11.28	7.82	0.67	5.00	0.00	0.00	0.37
39	Mangalsen	50.00	12.73	13.00	24.26	0.00	0.00	0.00	0.00
40	Manthali	33.11	27.83	19.48	10.87	4.50	0.00	4.22	0.00
41	Mirchaiya	40.59	10.56	17.53	21.08	6.11	0.00	0.45	3.69
42	Mushikot	56.95	5.25	15.55	14.97	4.97	2.31	0.00	0.00
43	Nijgadh	54.62	30.11	10.36	0.00	2.65	1.48	0.39	0.39
44	Pakhribas	32.63	17.12	17.30	23.98	0.59	4.76	0.46	3.16
45	Palungtar	50.59	20.98	13.76	0.82	0.00	0.00	0.00	13.84
47	Parshuram	51.18	38.36	10.45	0.00	0.00	0.00	0.00	0.00
46	Patan	26.93	3.81	17.31	49.60	0.09	0.00	0.35	1.90
48	Pyuthan	55.32	18.95	16.08	1.22	0.35	1.06	0.78	6.25
49	Rajapur	72.80	19.52	3.84	0.00	0.00	3.84	0.00	0.00
50	Ramechap	62.38	11.47	14.70	0.88	0.00	1.35	0.00	9.22
51	Rangeli	68.80	12.42	5.28	5.12	0.00	0.00	0.00	8.38
52	Rapti	55.87	17.27	15.05	11.81	0.00	0.00	0.00	0.00
53	Resunga	63.44	11.52	12.04	0.00	0.57	0.00	0.00	12.43
54	Sainamaina	60.44	22.77	7.76	4.42	0.00	0.75	0.00	3.86
55	Sanoshree-Taratal	47.60	33.28	3.24	4.95	0.00	1.04	0.49	9.40
56	Sanphebazar	45.24	10.95	19.05	22.86	1.90	0.00	0.00	0.00
57	Shani Arjun	32.48	33.65	16.55	5.68	1.89	0.00	0.00	9.75
58	Sharada	43.94	9.86	31.71	11.83	2.00	0.00	0.00	0.67
59	Shivraj	51.86	17.39	5.04	19.36	5.13	0.00	1.05	0.17
60	Suvaghat	63.75	26.55	9.70	0.00	0.00	0.00	0.00	0.00
	Average	**51.04**	**14.80**	**14.41**	**11.52**	**1.95**	**1.02**	**0.63**	**4.62**

Source; Pathak, 2017