MASTER THESIS

Waste to Energy: Solution for Municipal Solid Waste Management in Kathmandu Metropolitan City (KMC)

Submitted by

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UNIVERSITY OF TWENTE

Academic year 2018/2019

Abstract

The present trend of economic development with rapid urbanization come with enormous volume of MSW and global energy demand which is a worldwide concern. The problem is more severe in many cities of developing nations like Kathmandu. Hence, the proper municipal solid waste management (MSWM) system and innovating renewable energy alternatives are the primary issues to be addressed in Kathmandu Metropolitan City (KMC). The present MSWM system is limited to waste collection and disposal in landfill which is critically affecting environment and public health since long period.

Therefore, this research aim to investigate existing condition of MSWM and its possible impact in KMC. Further, it directed to analyse the changes needed on current MSWM system to be improved and to use the waste as resources for energy production by using available waste to energy (WtE) technologies. This particular study's assessment and analysis is typically based on secondary data and information through several literature from different sources. Researcher also interacted informally with officials from KMC to validate the data and information obtained from the secondary sources.

The concept of WtE approach, waste management hierarchy (WMH) and sustainable MSWM for the efficient and systematic MSWM is explored and anlaysed. It is observed from the investigation that the best and the most feasible WtE technology is anaerobic digestion (AD) for organic and incineration for plastic and paper waste in KMC since KMC produces larger fraction of organic, plastic and paper waste. The existing MSWM system does not consist of energy recovery process, as a result large waste are landfilled which is a least prefer option in WMH.

This research developed a new framework for MSWM for KMC which integrate WtE technology for energy recovery in the MSWM supply chain. It is believed that this element will not only play a significant role in reducing waste that goes to landfill but also generate renewable energy at the same time which contributes during energy demand in KMC. In addition, this proposed framework will also add value on reducing environment and public health issues.

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Acronyms

3R	Reduce, Reuse and Recycle
AD	Anaerobic Digestion
ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
BBC	British Broadcasting Corporation
CBS	Central Bureau of Statistic
CEN	Clean Energy Nepal
DEFRA	The Department for Environment, Food and Rural Affairs
DGIS	Directorate General for International Cooperation
ENPHO	Environment and Public Health Organization
EPA	Environment Protection Agency
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gas
HHs	Households
IBN	Investment Board Nepal
ISWM	Integrated Solid Waste Management
KMC	Kathmandu Metropolitan City
kWh	Kilo Watt Hour
LGCDP	Local Governance and Community Development Programme
MoEST	Ministry of Environment, Science and Technology
MoFAGA	Ministry of Federal Affairs and General Administration
MoFALD	Ministry of Federal Affairs and Local Development
MoHA	Ministry of Home Affairs
MoI	Ministry of Industries, Commerce and Supply
MoPH	Ministry of Population and Health
MoUD	Ministry of Urban Development
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MW	Mega Watt
MWh	Mega Watt Hour
NEA	Nepal Electricity Authority

NGO	National Government Organization
NPC	National Planning Commission
OAG	Office of Auditor General
PPP	Public Private Partnership
PPSF	Policy and Programme Support Facility
PSO	Private Sector Organization
SDG	sustainable Development Goal
SSWM	Sustainable Solid Waste Management
SWMRMC	Solid Waste Management and Resource Mobilization Centre
SWMTSC	Solid Waste Management Technical Support Center
ToE	Ton of Oil Equivalent
UN	United Nations
UNEP	United Nations Environment Programme
US	Unite States
USD	United States Dollar
WFD	Waste Framework Directives
WMH	Waste Management Hierarchy
WMW	Waste Management World
WtE	Waste to Energy

Acknowledgement

I would like to thank University of Twente for providing me incredible opportunity to do master. My sincere gratitude to my first supervisor Professor Dr. Maarten Arentsen for his continuous guidance and instruction on building idea and writing this thesis report. His positive and clear feedback always motivated me to focus on the subject matter that helped me to complete this report on given timeframe. Likewise, I would like express my sincere thanks to my second supervisor Professor Dr. Joy Clancy for her valuable support and guidance regarding the research idea and writing thesis report with very positive responses.

Furthermore, I would like to express my sincere appreciation to the course coordinator Ms. Rinske Koster for the continuous support and kindness during my study period. Likewise, my gratitude goes to Ms. Marjan Schonenberg for her help and study advisor, Ms. Sietie Zuidema for giving valuable advises regarding study. Similarly, my special gratitude to the director of this master programme, Professor Dr. Michiel Heldeweg and other professors and lecturers involved in this master programme.

Likewise, I would like to thank to officials of Environment Management Department of KMC for providing data and information regarding MSWM in KMC and their time. Likewise, my thanks goes to officials from AEPC for providing me information regarding biogas in Nepal.

I would like to extend my special gratitude to my family for their unconditional love, continuous support and guidance which are the key motivation and strength in my journey. Finally I would like to thank to my friends who helped me during my study time.

Sristi Silwal

Chapter 1

This chapter explains the overall background information of the existing scenario of municipal solid waste (MSW) and its management system in Nepal with particular focus in Kathmandu Metropolitan City (KMC). Waste to energy (WtE) technology as solution for the waste management is also briefly explained. Furthermore, it includes problem statement, research objectives, research questions, brief overview of methods used and finally the chapter ends with outline of the thesis report.

1.1 Background information

The volume of MSW has been increasing due to rapid population growth and disorganized urbanization in most of the developing countries such as Nepal. The management for this MSW is appeared as key environmental issue to be concerned. The rising economic development and fast growing urban population are the major reasons for the generation of enormous amount of MSW and Kathmandu is one of the city suffering from this problem.

Nepal government has designated 6 metropolitan, 11 sub metropolitan , 246 municipalities and 460 rural municipalities and that are gradually changing to urban center with development of infrastructures (LGCDP: PPSF UN, 2017). This is aiding the volume of solid waste and creating pressure to the environment. 18 municipalities of Kathmandu Valley[1] alone is producing around 850 to 900 tons of MSW per day (Environment department of KMC, 2018). The disposal and treatment of this massive amount of waste is a critical issues in the capital city where MSWM system is limited to collection and disposal in landfill and open dumping sites without taking consideration of environment and resources recovery. The proper management system and treatment of MSW in KMC is very poor. This has resulted unpleasant city environment and pollution due to the haphazard stockpiles (such as corners, market, riverbanks and open community space) of waste garbage (G.C. 2018).

Many aspects such as insufficient financial, human and technical resources and lengthy bureaucratic procedures as well as political influences are the major challenges for establishing appropriate MSWM system in Nepal. Likewise, the MSWM has never been considered as important issue in Nepal, because the demand for other public services such as food, road, energy and healthcare is high in all municipalities of the country take priority (ADB, 2013).

Many European countries has adopted the integrated solid waste management (ISWM) system where landfilling is the least preferred option and their share of wastes goes to the landfill is in very less amount when compare to total generated waste (WMW, 2013). Example can be taken from

[1] *Kathmandu Valley comprises of three district which are Kathmandu, Lalitpur and Bhaktapur.*

Netherlands, where only 2% to 3 % of the total generated waste end up in the landfill site[2] (WMW, 2013). The comparison of Nepal with developed countries does not seem feasible, nevertheless, the adoption of the knowledge, efficient technology, and sound governance practice can be the inspiration for developing countries like Nepal to move forward towards efficient MSWM. Nepal is not yet in this progressive pathway and still practicing the traditional MSWM as generation-collection-disposal approach. Concerning MSWM process, the least preferred options is the landfilling which can cause the adverse impact to the environment and public health.

Regarding the MSW composition in KMC, large volume of MSW is shared by organic fraction which is directly dumped in landfill and some inorganic waste are either sold to neighboring country or in local market and remaining waste dumped into landfill. The organic waste can have a potential of generating energy via WtE technology and rest of the waste can be reused and recycled which can contribute to reduce the MSW problem in KMC. Hence, the adoption of appropriate WtE technology can be the promising solution for the MSWM in KMC and the generated energy can contribute to meet energy demand. For this, the current system requires to transform into more practical and environment friendly system for MSWM in KMC.

1.2 Problem statement

As mentioned above that MSWM is a major problem in Kathmandu city as it is in many cities of developing countries. The rapid population growth and the continuous economic development for meeting their demands is a major cause. For instance, Nepal's urban population is increased by 3.18% annually (CBS, 2011). About one third of Nepal's urban population is living in the capital city, Kathmandu and the population is growing even faster by 4.78% annually (CBS, 2014) increasing the waste problem. The lack of proper and effective MSWM system in KMC has created risk on quality of environment and human health.

Despite the initiatives of the Government of Nepal- by amending legislation, such as the Solid Waste Management Act in 2011, the problems has not diminished. However, adoption of WtE technology in MSWM system can be the appropriate solution to deal with this problem. Hence, in this thesis research, researcher has analyzed the different WtE technology and investigate suitable WtE technology for KMC according to the MSW composition. However, the WtE concept and technology is new and hardly explored in Nepal.

[2] https://waste-management-world.com/a/landfill-a-victim-of-dutch-success

1.3 Research objectives

The general research objective of this study is to develop knowledge on how Kathmandu could reduce the environmental impact from its current MSWM practice by adopting waste management technology based on WtE.

Specific objectives are:

1. To assess and analyse the current municipal solid waste management (MSWM) practice
2. To identify the composition of MSW and its total volume through secondary literature
3. To assess and analyse the impacts from current MSWM
4. To identify the changes in current MSWM practice to organize WtE system
5. To design WtE system framework (model) for efficient MSWM system in KMC

1.4 Research question

The main research question:

What changes are needed to use the waste as resource in Kathmandu Metropolitan City for energy production?

Sub questions:

1. How is the current MSWM system in KMC organized with what results?
2. How could a MSWM system according to concept of WtE look like for KMC?
3. What changes in the current MSWM system of Kathmandu are needed for transforming it into a WtE system?

1.5 Research approach and methods

This research is basically based on desk study with the help of various literatures as required. Therefore, the method of this research is simple however researcher tried to apply the systematic research design to conduct study smooth and in a systematic manner.

The research design refers to the strategic framework that interlink research question and execution as well as it serves to implement the research strategy (Durrheim, 2004). Simply, the research design is the overall strategy to incorporate different components of the research in a logical and organized fashion to answer the research questions. Therefore, this section covers the approaches and methods to answer the research questions in a strategic way to generate recommendations of proper MSWM system based on waste to energy approach in KMC.

Verchuren and Doorewaard 2010, defined research material as *"defining and operationalizing the key concept of the research objectives and the set of research questions"*. This particular research is conducted using secondary data and information. Therefore, different information and data are collected through various in-depth literature review from several scientific research paper, relevant documents from various organizations, observation, and informal key informant interview with stakeholders within research unit[3].

Several literature about MWSM system and its problem are assessed and analyzed particular focus on KMC. Likewise, observation and depth analysis of WtE approach, specific focus on generating energy from organic, plastic and paper waste is carried out to know its feasibility in KMC.

In addition, key informant interview with officials (who are responsible for MSWM) provided information to justify the collected data and information from the secondary sources. For this, the informant from KMC office and from Alternative Energy Promotion Centre (AEPC) were asked information related to the research questions. These information from informant are used to validate data and information obtained from different secondary literature and documents. The table on appendix 1 describes the data and information required to answer the research questions, sources of the data and method for accessing and analyzing data for answering the research questions. For this, analytical framework is developed and qualitative analysis methods is applied in an exploratory approach which brought the comprehensive perspective on sustainable MSWM system for KMC.

1.5.1 Schematic presentation of analytical research framework

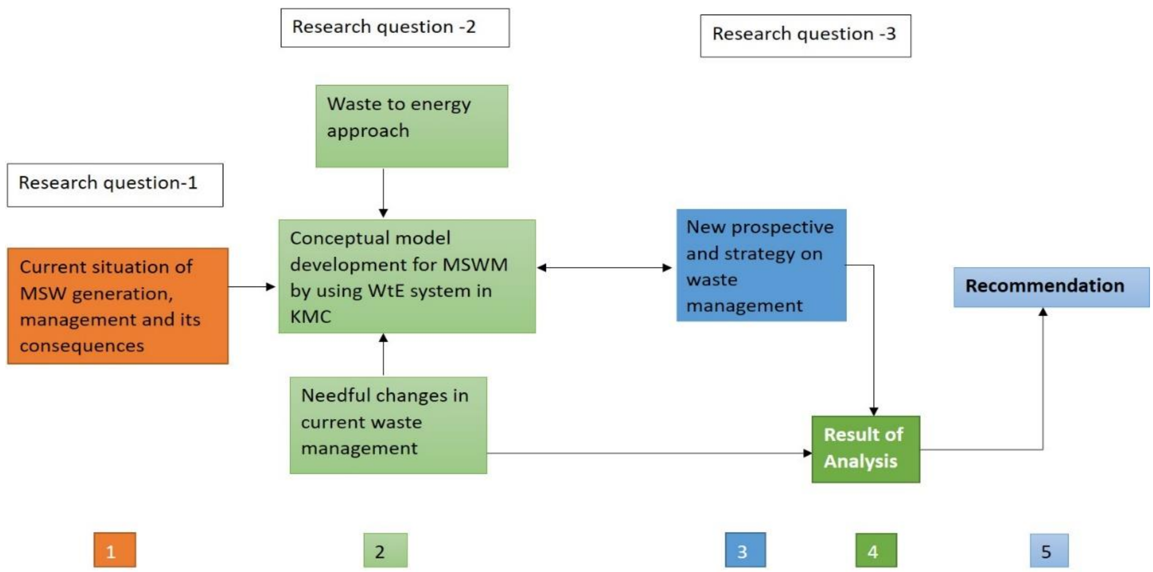

Figure 1: Schematic presentation of analytical research framework

[3] *Municipal solid waste management is the research unit in which waste to energy (WtE) approach for MSWM for KMC is the observation unit*

The data and information are analysed in a following sequential order.

1. First step in analytical framework helped to assess and analyse the current status of MSWM in KMC with the help of literatures and available documents. Also, the present challenges arise from unsystematic MSWM is assessed and analysed.
2. Second step follows the creation of an inventory of WtE approaches and technologies particularly based on secondary literature. This step forms a conceptual model for applying the WtE system in KMC.
3. The second step helped to build the third step to bring the new perspective with conceptual model which can be used to manage MSW in KMC. This step built next step as main analysis of this result.
4. In this step, the finding and results from this sequential order is vigorously analysed with effective conclusion that can be applied for the implementation of WtE system in KMC.
5. This step brought the recommendations specifically based on result of analysis of this particular study. This step answered the main research question with recommendation of needful change in current MSWM system with new design of MSWM system based on WtE technology to use waste as resource for energy production in KMC.

1.5.2 Research boundary

The research boundary explains the limitations of research performed and its consistency. The research limitations for this particular study are described as: experiment such as conversion of waste into energy using technology is not performed for the analysis. The research covered mostly the qualitative analysis however, for the quantitative analysis, data on MSW include only households, commercial and institutional wastes while other MSW produced from public places and medical waste from hospital are not analysed which requires special procedures. In addition, the data and information about the MSWM in KMC is not adequate and not updated since long time. Hence, this research is ultimately reliant on only accessible data. It is needed that KMC update data in regular basis so that the intervention on MSWM will be well planned and up scaled. Besides this, different dimension of sustainability such as social which include the social issue related to informal worker whose livelihood is dependent on current MSWM activities could not be assessed adequately since this research is particularly focused on technical analysis part and also due to time limitation. Likewise, economic analysis such as cost benefit analysis of WtE technologies has not been considered due to time limitation and designed research framework. In addition, political dimension has not been explained explicitly whereas different policies in different time period regarding SWM in Nepal has been explained and analyzed to formulate recommendations.

1.5.3 Statement on research ethic

For this research, ethical sensitivity for collecting data and information is considered as irrelevant since there is no involvement of human and animals. Nevertheless, the main goal of this research is to develop a new framework for MSWM for KMC, hence, the ethical research principles are valued and followed during data assessing and gathering, analysis and reporting. Likewise, regarding ethical issues or conflict of interest in this research project, it is believed that risk and inconvenience are minimum in case of tackling data and information. Likewise, this research finding will not deliver such unethical issues, conflicts and dilemmas.

1.6 Outlines of the thesis

This research report is structured into five chapters comprising this chapter. Chapter two provides the description of study area (KMC), Current MSW generation and management in Nepal and KMC with discretion with various MSWM elements, institutional arrangement for the MSWM, overview on solid waste management policy, law and legislation and stakeholder involvement in MSWM system in KMC. Furthermore, it explains the waste management hierarchy system for MSWM. Chapter three elaborates more on different WtE technology and its application for energy recovery. It also presents the energy situation in Nepal so that this background information helps to interlink between waste and energy. Similarly, this will include the opportunity of energy recovery from waste with energy calculation, and this chapter end with potential foreseeable design for MSWM system which integrates WtE technology. Hence, chapter three primarily provide the answer of second sub question. Chapter four is basically for the comparison of current MSWM system and new proposed design of MSWM for KMC which also describes different factors/aspects for transforming the current MSWM system to more sustainable management system based on WtE technology approach. Further, it analyses the need for changing the current MSWM system in KMC. Chapter five delivers the conclusion and recommendations. This chapter concludes all the chapters and answer the research main question. Furthermore, it includes overall reflection of this research.

Chapter 2

This chapter covers the basic overview of the main concept required by this research which are based on the prior research, scientific journals, reports, data and information from different sources. For this, the chapter begins with description of the study site, current MSWM system and institutional arrangement for the MSWM. In addition, the existing SWM legislation and policy are described at the end of this chapter.

2.1 Description of the study area

Kathmandu Metropolitan City lies between the latitudes $27^0$32'13'' and $27^0$49'10" to the north and longitudes $85^0$11'13" and $85^0$31'38" to the east with an altitude around 1400 meter above sea level (masl) (CBS, 2012). It has total area of 50.67 sq. km (KMC, 2019). Kathmandu is the capital city of Federal Democratic Republic of Nepal and is also the administrative center of Nepal (UN, Habitat, 2015). The highest population growth rate was recorded in Kathmandu district by 61.23 % during the last decade (CBS, 2012). KMC is sub divided into 32 different wards[4]. Kathmandu is the nation's most populous city which comprises 1,003,285 population (which is 24.3% of total urban population) with 254,764 households and has the population density of 20,289 per sq. km (CBS, 2012). The resident of KMC is escalating by 4.78% annual growth rate (CBS, 2014) which is recorded as the highest expanding metropolitan area in South Asia (World Bank 2013).

[4] *Municipality is divided into further local unit as different ward according to administrative division of Nepal.*

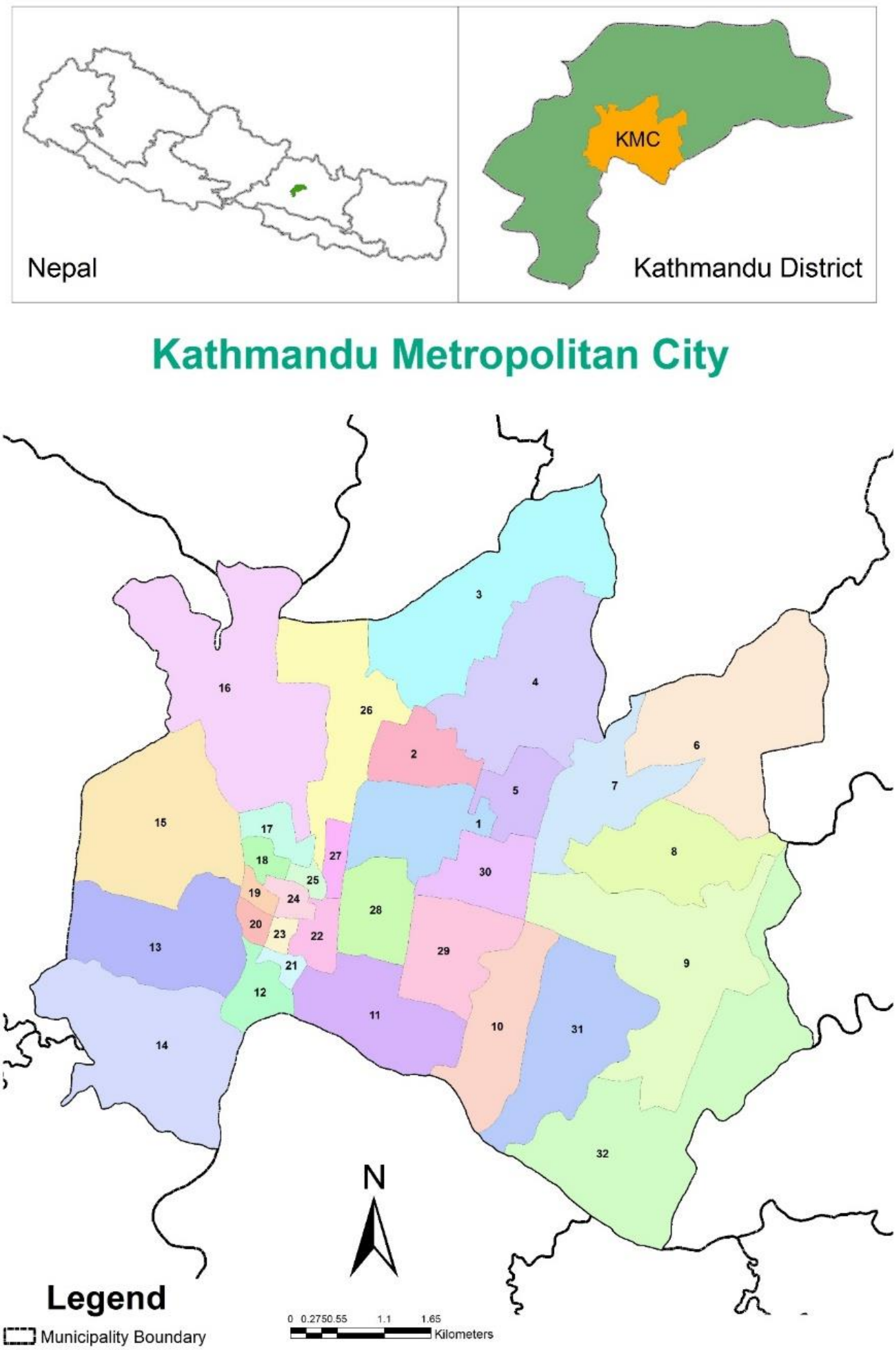

Figure 2: Map of the study area (Kathmandu Metropolitan City)

2.2 Municipal solid waste situation in Nepal

In Nepal, generation of solid waste depend upon the geographical region. There are three distinct region according to altitude range which are mountain, hills and Terai (flat land). The generation of average households waste of mountain region (northern part), hilly region (mid hills) and Terai (southern part) region are 0.49 kg/HHs, 0.72 kg/HHs and 0.88 Kg/HHs respectively and average per capita waste generation in Nepal is 0.32 kg/day (ADB, 2013). ADB surveyed 58 municipalities to assess the MSWM during 2011 to 2012. This report reveals that the total MSW from these municipalities is 524,000 tons per year. The composition of the waste is mostly recyclable and non-hazardous and the volume of the waste per capita is less in comparison to developed countries (ADB, 2013 and UNEP, 2001). The dominant source of MSW generation is households in Nepal. The composition of municipal waste are generally organic, plastics, paper and paper products, glass, metals textiles, rubbles and leather and others. The organic waste shares the highest volume in comparison to other waste in Nepal. However, the volume and composition of MSW is governed by living standard and economic status of the community and households (ADB, 3013). The following figure 3 shows the MSW composition in 58 municipalities of Nepal in 2013 and figure 4 presents the different disposal methods used by the municipalities for dumping their MSW

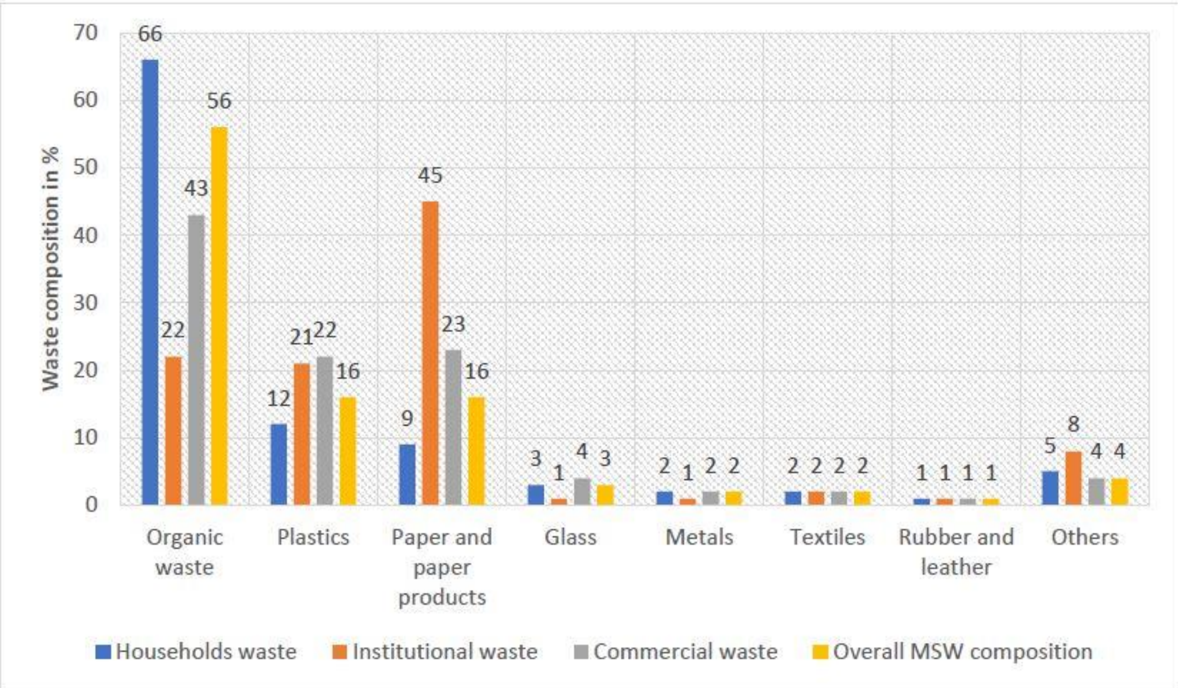

Figure 3: The composition and type of municipal waste in 58 municipalities in Nepal

Source: Adb.org, 2013

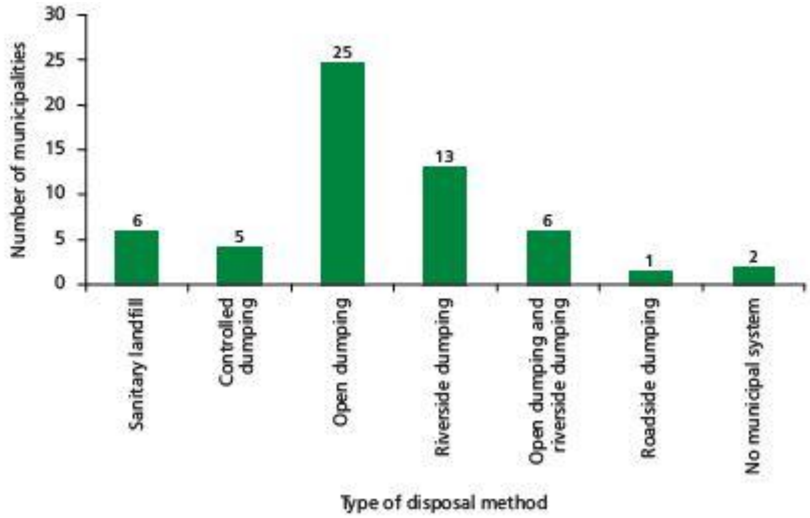

Figure 4: Type of disposal method for dumping MSW in municipalities in Nepal

Source: ADB, 2013

2.3 Waste generation and its composition in KMC

Waste volume and its composition are the key components though they are dependent on different variable such as urbanization, living standard of community, population growth and economic activities should be addressed during the formulation of plan and system for MSWM (ADB, 2013). The municipal waste in KMC is generated from residential waste from household and nonresidential waste from commercial buildings and institutions (ADB, 2013). The table 1 illustrates the total waste generated from different sectors in KMC where total waste generated per day is 466.14 tons which consists 233.07 tons/day from households waste and 203.49 tons/day from commercial waste and 29.58 tons/day from institutional waste (ADB, 2013). The waste has been increased as the population growth is constantly increasing in Kathmandu and currently, about 600 to 700 tons of waste is generated per day in KMC[5]. The per capita waste generated in KMC is 0.23 kg/person (ADB, 2013).

Table 1: Solid waste generation and collection efficiency in Kathmandu Metropolitan City

Average household waste (kg/day)	Average per capita HH waste (kg/capita/day)	Total HH waste (tons/day)	Total commercial waste (tons/day)	Total institutional waste (tons/day)	Total MSW generation (tons/day)	Estimated waste collection (tons/day)	Collection efficiency (%)
1.10	0.23	233.07	203.49	29.58	466.14	405	86.90

Source: ADB, 2013

2.3.1 Municipal solid waste composition

Office of the Auditor General (OAG) in 2015 stated that MSW composition is essential equally as of its quantity because every waste has its own characteristics and this has to be understood to manage

[5] *Based on the information obtained from deputy director of environment management department, Teku.*

different waste separately and some waste needs exceptional treatment as well. Basically, MSW consists of organic and inorganic waste. The organic waste is the biodegradable waste which comprises green waste, food waste and wood waste and can be broken down into carbon dioxide, methane or simple organic molecule in the presence of microorganism. Inorganic waste generally comprise of paper, plastic, metal, rubber, leather and textiles and others (Ghanimeh et al., 2012). The composition of MSW depend upon the culture and tradition of inhabitants, consumer lifestyle, food habits, climate and economic status (ADB, 2013). The following pie charts represent the overall waste composition from different source in KMC.

Household waste composition

The household waste composition of KMC is shown by figure 5 which noticeably illustrates that organic waste shares the large fraction of total waste which is 64.24% followed by plastic (about 16%), paper (about 9%), glass (about 9%) and textiles (3%). Metal, rubber and leather and other inert waste share about 4% of total waste.

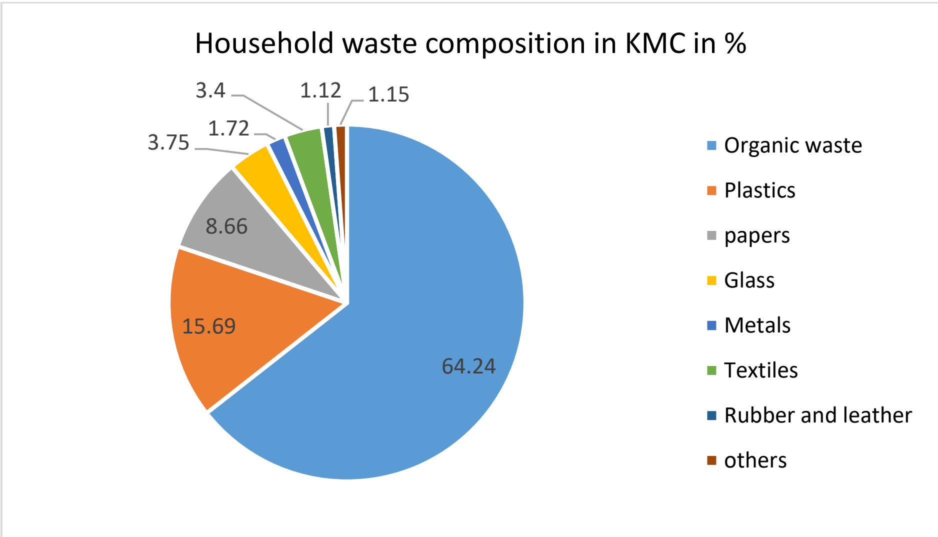

Figure 5: Household waste composition in KMC in %

Source: ADB, 2013

Institutional waste composition

Institutional waste from school, colleges and office consist highest percentage of paper (approx.44%) which is followed by plastic (approx.25%) and organic waste (approx.20%). Other waste such as glass, metal, textiles, rubber and leather and other waste cover about 11%. It can be noticed that the high amount of plastic and paper mean it can be reused and recycled.

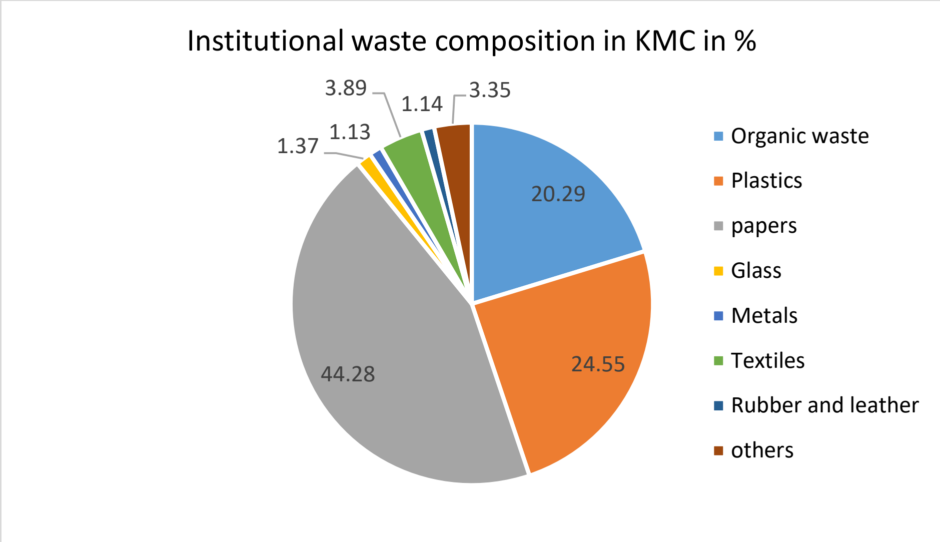

Figure 6: Institutional waste composition in KMC in %

Source: ADB, 2013

Commercial waste composition

Commercial waste composition shows that organic waste fraction is lower that other inorganic waste, though it shares about 45% solely in total waste. This also signifies that organic waste has good prospect to convert into energy and compost whereas other waste such as plastic and paper which share about 48% of total waste can be reused and recycled.

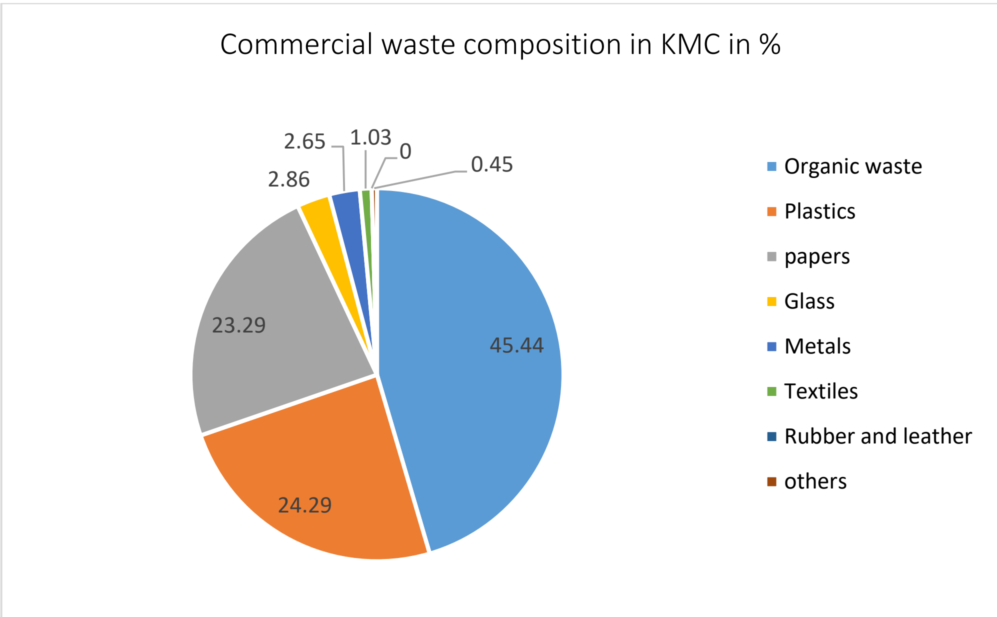

Figure 7: Commercial waste composition in KMC in %

Source: ADB, 2013

Total municipal composition in average in KMC

The figure 8 shows that the organic volume of waste is highest (43%) which is followed by paper (25%), plastic (22%), textiles (3%) and glass (3%). Other waste such as metals, rubber and leather waste comprise about 4%. The maximum share of organic waste in MSW indicate that it has great potential for energy recovery and compost. The maximum organic waste require frequent collection and removal of waste from source (ADB, 2013) due to its fast decomposition character. It is observed from the data that inorganic waste comprise about 55% of total MSW such as paper, plastic, glass, textile, rubber and leather which can be primarily reused and recycled from the waste recovery process and the rest is inert waste material (only about 2 %) has to go landfill.

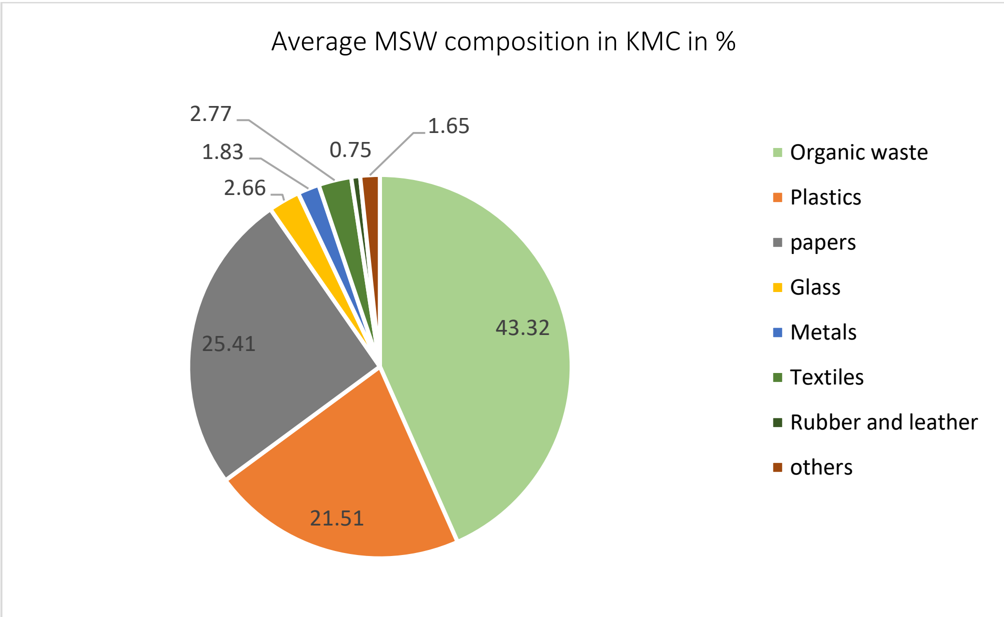

Figure 8: Average waste composition in KMC in %

Source: ADB, 2013

Organic waste generation

Household is the main source of MSW in KMC which comprise 64.24 % which is followed by commercial waste about 45% of total MSW while institution is the least in total waste (20%). The figure 9 noticeably illustrate that the share of organic waste from household is high in total MSW.

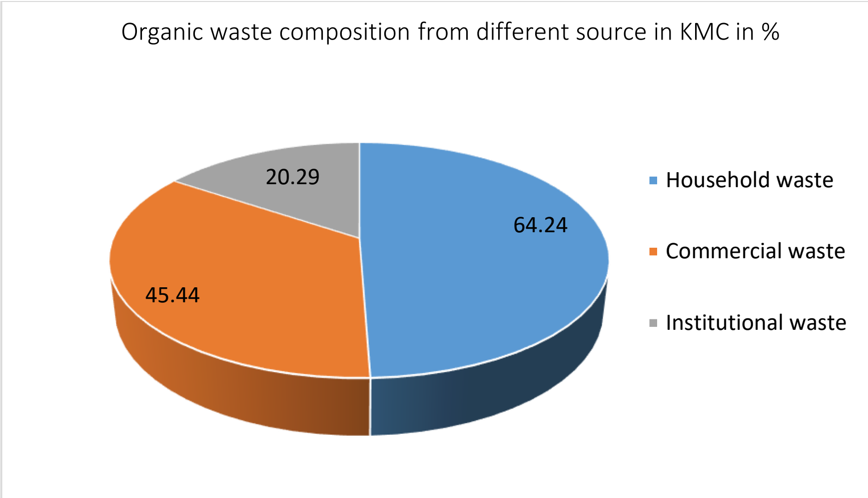

Figure 9: Organic waste composition from different source in KMC in %

Source: ADB, 2013

It is observed that the organic, paper and plastic are the dominant waste fraction of KMC's MSW which share around 43%, 25% and 22% of total waste respectively. About 57% of MSW is inorganic which shows the good prospective of waste recovery or recycling excluding approximately 2% of inert waste material that can be landfilled.

It can be distinctly observed that the use of plastic and paper has been increasing which is now an integral part of the lifestyle of people where every products and goods are packaged mostly by plastic and paper over the years. This can be seen in plastic waste data in KMC's MSW composition that there appears to be a significant increased from 5.4% in 2005 to 12% in 2007 (Dangi et al., 2008 and Dangi et al., 2011). Furthermore, the plastic in MSW has increased to 22% approx. in 2013 (ADB, 2013). The rapid increase in use of plastic materials might be due its several functions as well as light and durability and cost effective.

2.3.2 Current solid waste management system in KMC

The municipal waste management system in KMC is very basic and it does not have proper waste management practice. The following flow chart (figure 10) of waste management shows the overall waste management practice in KMC. This chart clearly shows that the system lacks formal recycling and reutilization facilities and most of the waste ended in Sisdol landfill site located at Okharpauwa, Nuwakot district. Likewise, the MSWM supply chain completely lacks the waste segregation at source.

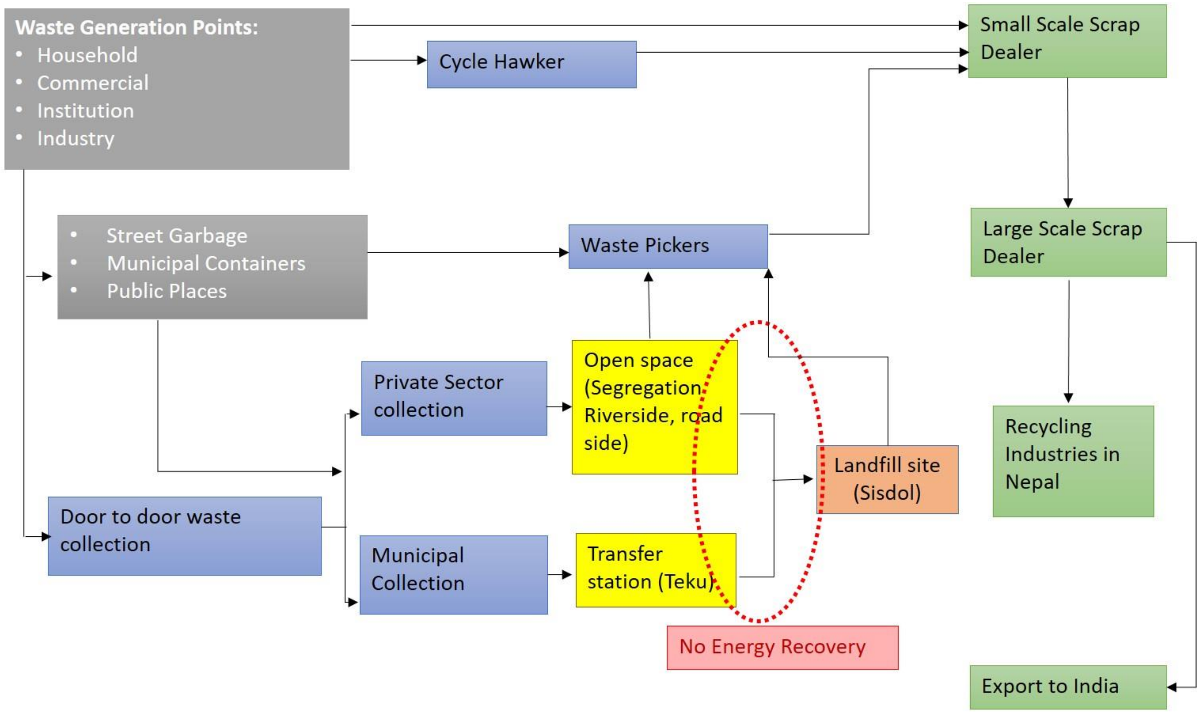

Figure 10 : Current MSWM system in Kathmandu Metropolitan City (KMC)

Note: This flow chart is developed from reference of Luitel and Khanal, 2010 and KMC, 2019

2.3.3 MSW collection, transportation and segregation

The study conducted by ADB in 2013 in 58 municipalities of Nepal found that about 30 % household practice segregation of waste at source. It means that about 70% household goes for collection and disposal by the municipalities in the form of mixed waste. Generally household from rural areas segregate kitchen waste for their domestic purpose e.g. feeding cattle. In Kathmandu, it is also found that due to lack of separate collection and treatment method sometimes segregated waste at source also mixed again during collection and transportation.

Well-organized and planned waste collection, its transportation and segregation from source are another significant elements of the MSWM system in municipality. The collection methods employed in most of the municipalities of Nepal including KMC are door to door collection, container service, and roadside collection from container or open pile of waste. Although KMC is accountable for the MSW collection and transportation to landfill from 32 wards of KMC, there is a presence of partnership between different private sector organizations and NGOs (OAG, 2015) for this activity. According to ADB 2013, it was estimated that 405 tons waste per day was successfully collected with the efficiency of 86.90% (table 1) but due to the lack of appropriate scientific data system, this data could be an overestimation by the municipality (ADB, 2013). The lack of research on waste collection and its quantity, transportation and storage could be one of the primary cause of restriction for developing efficient SWM plan and system.

Report published by OAG in 2015 reported that there are 1100 employees including from administration staffs were involved in the SWM activities, where 135 drivers were collecting and transporting waste from KMC to landfill site in 2014. Data presented in the table 3.

Likewise, there are 152 different vehicles allocated for collection and transportation of the MSW of KMC in which only 99 vehicles are functional (Environment Department of KMC, 2018). Furthermore, the existing vehicles are mostly old and are not in proper condition. This added the nuisance in environment due to overloaded waste in limited vehicle and not covered properly during collection and transporting to landfill (OAG, 2015) and sometimes due to limited number of vehicle cause delay in transporting of waste. This lead to the mass accumulation of waste along the roadside, open space and river side for a long time that creates threat to human health and environment. Furthermore, the monsoon rain damaged the road to Sisdol landfill site which obstruct the collection and transport of waste from KMC which results into unbearable stench emanating from waste littered in roads and open space (The Kathmandu Post, 2019) which portrays this scenario by the figure 11. Sometimes this unpleasant smell can lead to create public pressure to the concerned authority to respond and act quickly.

Figure 11: Garbage pile in road side inside Kathmandu city

Source: The Kathmandu Post, 2019

Figure 12: Waste pile in transfer station, Teku ready to transport to landfill without segregation

Source: Photo taken by researcher on July 1st 2019

Figure 13: One of the main river of KMC is littered by waste

Source: Photo taken by researcher on July 1st 2019

2.3.4. MSW transfer station (Teku) and final disposal at landfill (Sisdol)

MSW transfer station and its final disposal is equally important in entire waste management supply chain since disposal is final step after the transfer of waste in MSWM system. Teku transfer station was built for storing waste before transporting to Sisdol landfill, since transporting huge volume of waste in small vehicle over long distance and poor quality roads is often difficult. That is why, the waste collected from KMC is taken to Teku transfer station and then is transferred to landfill site. This transfer station is extended to 2 hectare area (CEN and ENPHO, 2004) and can hold 10,000 tons of MSW which is surrounded by residential area (OAG, 2015). Waste from 12 ward of KMC is taken to this transfer station from municipality and rarely separate recyclable and reusable waste. KMC transport this waste to the landfill for final disposal and here informal waste picker segregate recyclable waste from the bulk. In case of PSOs, they transfer waste in open public place such as road side and river side after collection from different collection points of 20 wards of KMC. Informal waste picker separate recyclable waste from this public area. However, most of the time, PSOs transfer directly to landfill side for final disposal. The sorted waste from informal waste picker and also from PSOs are sold to local scrap dealer (both small scale and large scale wholesaler), small recycling industries in Nepal and also exported to neighboring country India for further processing to produce new products. There is no sophisticated system used for segregating waste since segregation process is done by hand without proper equipment.

Figure 14: Teku transfer station (surrounded by residential building)

Source: Photo taken by researcher on July 1st 2019

Figure 15: The Sisdol landfill for dumping MSW from Kathmandu in Okharpauwa, Nuwakot district

Source: KMC, 2018

According to department of environment of KMC, 2018, around 900 to 1000 tons of MSW is transported and dumped into the landfill daily from all the municipalities of Kathmandu Valley including KMC. However the Sisdol landfill is a semi aerobic sanitary landfill, so it does not meet the standard of sanitary landfill of national standard guideline for municipality prepared by SWMTSC which exposes surrounding environment to pollute air, contribute to climate change (GHGs emission) and water (from leachate[6]) (OAG, 2015). Waste transferred in this landfill are basically organic and is biodegradable which can be converted into bio energy and compost if appropriate technology is implemented. However, due to lack of effective SWM system, these valuable waste are dumped and exploited in limited area of landfill. OAG 2015 reported that the Sisdol landfill overly used whose life span is already expired since it was designed for 2 to 3 years in 2005.

[6] *Leachate is the liquid material drains from landfill which contains dissolve and suspended materials (organic, inorganic, heavy metals and pathogen) (Osterath, 2010 and Raghab et al., 2013) that pollutes the surface and ground water and has potential to affect human health and environment* (Mishra, Tiwary & Ohri, 2018). *Leachate results from the rain water that percolate the landfill and also the moisture that present in the MSW (Raghab et al., 2013).*

Figure 16: Untreated leachate discharge from Sisdol landfill affecting environment

Source: KMC, 2018

2.3.5 Resource recovery

Resource recovery in MSWM involves with the processing of recovering energy or different product from MSWM for another use. This strategies primarily aims to reduce environmental, economic and social burden for the municipality from the MSW to be landfilled[7]. The resource recovery in waste management hierarchy stand as reduce, reuse and recycle which ultimately helps to reduce MSW and generate energy.

In the case of MSWM in KMC, resource recovery is not performed formally and adequately although the SMW Act 2011 has emphasized on 3 R principle of waste management, reduce, reuse and recycle. However, some resident of KMC has been practicing 3R waste management at household level such as composting from organic waste.

Recycling

Recycling of MSW in KMC is basically carried out by non-government body such as NGOs, CBOs, private sector, informal group including waste picker and scavengers. The recyclable waste from HHs,

[7] https://www.encyclopedia.com/environment/encyclopedias-almanacs-transcripts-and-maps/resource-recovery (accessed on August 10th, 2019)

commercial and institutes are collected by private sector and sell to scrap dealer and finally export to India for further processing by large scale wholesaler as shown in the MSWM flow chart (figure 10). These waste generally contain paper, bottle, and metal and about 150 tons/day of these waste are collected in Kathmandu Valley including KMC (SWMTSC, 2013). However, these private sectors are operating this activities without obtaining license and coordinating with public authority as SWM act 2011 mentioned that the entire MSWM activities should be carried out by municipality (OAG, 2015).

The following figure 17 represent informal sector involvement in the informal recycling system in the developing countries. And this informal recycling system consists of at least four main categories depending on the place of waste recovery which is resemble to the current scenario of MSWM in KMC. The first is itinerant waste buyers buy specific recyclable waste from door to door. Second is street waste picker who collects waste from mixed waste thrown on the road and public places. Third is municipal waste collection crew where secondary raw material are recovered from container or truck that transport waste to landfill. Fourth is waste picking from dumping area where scavengers segregate recyclable waste from final disposing waste (Wilson et al., 2006). These actors play an important role in collection of reusable and recyclable waste in KMC.

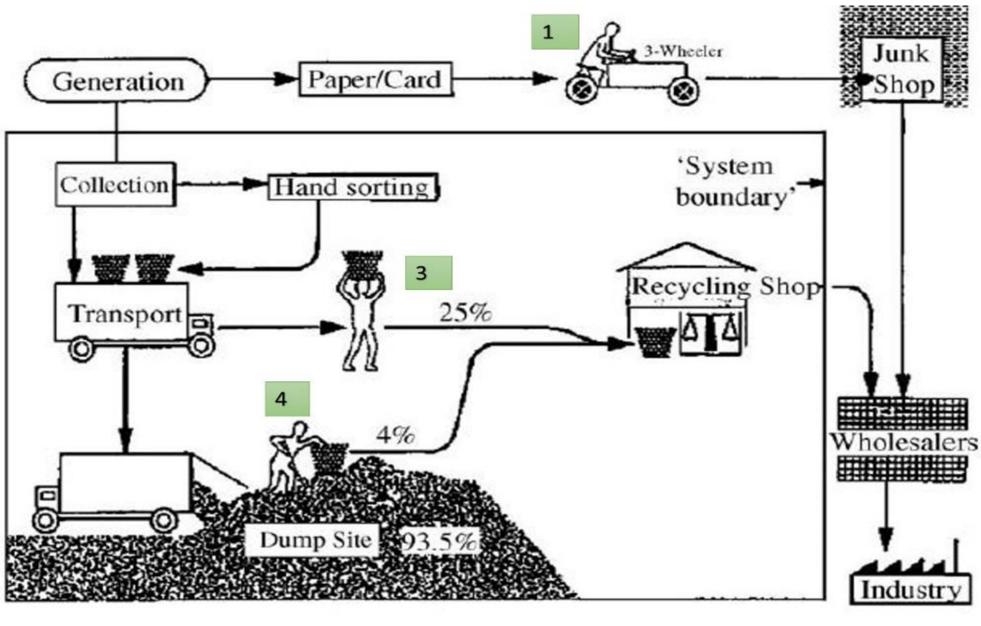

Figure 17: Informal sector engagement in recycling of MSW in KMC

Source: Wilson, Velis & Cheeseman, 2006

Composting and Energy recovery (WtE)

The composting of biodegradable waste is another resource recovering process. The MSW composition is highly organic with great potential for composting as well. However, this has been practiced in household level for kitchen garden and some private company in small scale. WtE is the process of recovering energy from waste is a new concept in Nepal. However in 2016, KMC started a pilot project, biogas plant in Teku to generate energy from vegetable waste collected from *Kalimati* vegetable market which use 3 tons vegetable waste per day and generate 400 kWh/day energy and 300 m^3/day of biogas and 200 kg/day of compost (KMC, 2018). The generated energy is used in KMC office. The plan is to replicate this project to large scale, however, no plan has been documented yet.

2.3.6 Public awareness

Most of waste are generated from households in KMC. Hence, the public participation and consultation is essential for the establishment of efficient and robust SWM system. One of the key challenges of SWM is lack of public consciousness and knowledge on SWM that is also observed in case of MSWM in KMC (ADB, 2013). According to SWM act of 2011, Nepal, waste segregation as organic and inorganic is most important at source and this should be recognized by public. For this, environment department of KMC had formed a community mobilization unit which is working closely with different groups of community for raising awareness and providing them with training and necessary support and also promotion of 3R principle for the efficient SWM in KMC (Water Aid, 2008). Although providing and delivering all mentioned awareness programme and effort delivered by KMC, many people and even staff of municipality are still unaware of proper SWM (ADB, 2013). OAG 2015 stated that various organization are actively involved in awareness programme for sustainable SWM and cleaning up activities implemented in school level as well. However, the waste separation at source and haphazard disposing of waste is still in practice in KMC.

2.3.7 Special waste management

Special waste refers to the waste generated from construction and industries, waste from medical centers, lab and dead animals. These waste need a careful and systematic approach to be managed separately from MSW and to ensure that it is not mixed with MSW. In case of KMC, though most of the hospital use incinerator to burn these special waste, however, there is no proper slaughterhouse seen and dead animal are mostly thrown in a river, open public space or dumped in landfill (ADB, 2013).

2.4 Institutional arrangement for the MSWM

SWM is one of the basic essential services that need to be provided by municipalities to keep urban centers clean under the Local Government Operation Act 2017 and Solid Waste Management Act of 2011 and Regulation 2013. Likewise, solid waste management technical support center (SWMTSC) is the key stakeholder for providing support to municipalities in SWM and Ministry of Federal Affairs and General Administration (MoFAGA) facilitates municipalities for finding technical and financial support from international organizations and also support in MSWM activities in overall (OAG, 2015). SWMTSC is an autonomous body under the Ministry of Federal and Local Development (MoFAGA). MoFAGA is responsible for formulating policies, implementing, monitoring and also reviewing all the policies and strategies related to sanitation and sewerage, MoUD is responsible for maintaining sanitation and drainage within Kathmandu whereas SWMTSC works as monitoring and regulatory mechanism for the MSWM. This clearly indicate that Nepal government has good institutional arrangement for the MSWM but they do not have clear enforcement regulation related to SMW promotion. Similarly, Department of Urban Development and Building Construction (DoUDBC) provides technical support on infrastructure development and Department of Environment provide standard for pollution control, EIA and environmental monitoring. Municipalities are the most important stakeholder for implementing the MSWM activities in Nepal. The flow chart (figure 18) shows the larger picture of various stakeholder involvement and their responsibilities for the SWM in Nepal.

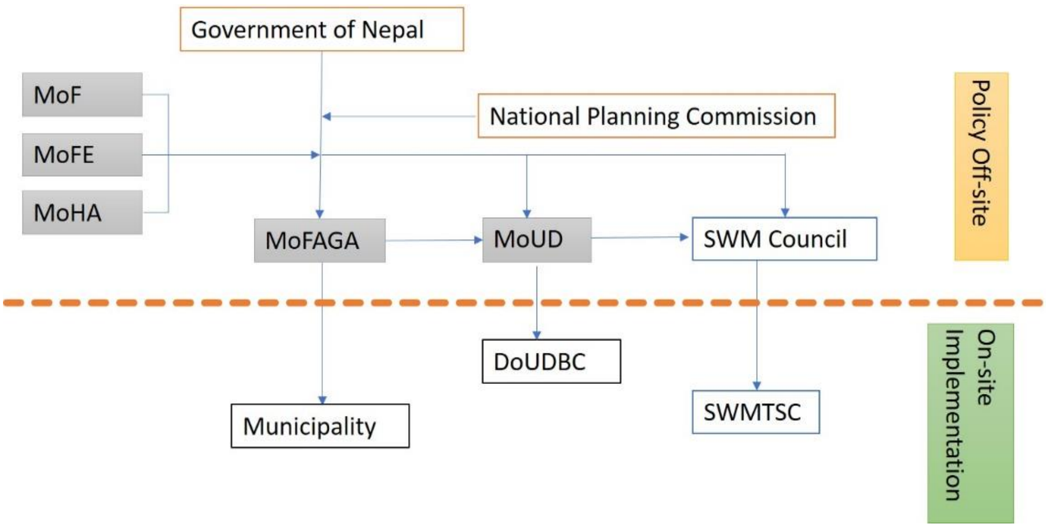

Figure 18: Institutional arrangement for the MSWM in Nepal

Note: Reproduced from the reference of Disaster Waste Management: Policy, Strategy and Action Plan, Government of Nepal, UNEP and LEAD Nepal.

Many municipalities in Nepal have a separate section or unit for SWM purpose within their organizational structure. Most waste management units are either part of the Social Development Section, Planning and Urban Development Section, or Community Welfare Section of the municipalities (ADB 2013). The figure 19 represents the KMC's institutional structure for overall functions including MSWM in KMC. MSWM is included in environment protection programme, hence, environment management department is responsible for the MSWM activities. Further this department is divided into 4 division according to different functions. MSW division is accountable for taking care of MSWM in KMC. This division is particularly focused on overall activities under different element of MSWM and further divided into MSWM section, Landfill site Management section and Activities Mobilization Section.

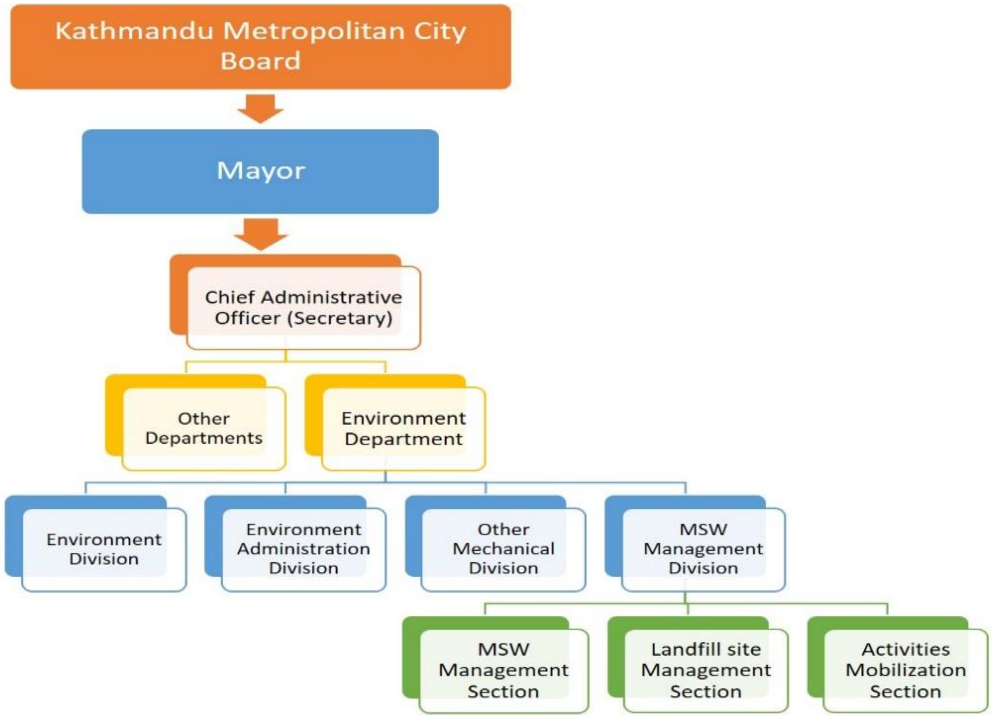

Figure 19: Institutional arrangement of KMC for MSWM

Source: KMC, 2019

2.5 Resource allocation for waste management

2.5.1 Financial and technical resources

Financial and technical resources are always key elements when planning for implementing efficient and robust MSWM system. The distribution of financial and technical resources varies among the municipalities in Nepal. The table 2 shows the budget allocation for municipality and MSWM activities in different fiscal year. About 24% of the total municipality budget in average is allocated for the MSWM as environmental protection. According to ADB, the major portion that is 60-70% of allocated budget for SWM in KMC is used for waste collection and street sweeping where 20-30% budget is used for transportation and remaining amount is disbursed for disposal of waste (ADB, 2013). It is observed that major chunk of money is utilized only for collection system. Another significant reflection from this is the allocated budget has been underutilized and surprisingly large amount of this budget is used for the salaries and facilities for the staff-involving in street cleaning and maintenance and fuel cost which is justified by the table in appendix 2 (OAG, 2015). Also, this has been observed from the data (appendix 3) that municipality is mainly focusing on waste collection and its transportation in landfill whereas, landfill and transfer station management is being least highlighted in case of disbursing budget.

Table 2: Total allocated municipal budget and SWM budget in KMC from fiscal year 2010/11 to 2013/14

Fiscal Year	Total municipal budget (NRs Million)	Budget allocated for MSWM (NRs Million)	Budget allocated for MSWM (Million USD)	% of allocated budget for MSWM
2010/11	1212.85	278.61	2.53	22.97
2011/12	947.41	253.13	2.30	26.72
2012/13	1900.00	443.10	4.02	23.32
2013/14	2630.89	621.70	5.64	23.63
Average				**24.16**

Note: 1 USD is equivalent to 110.17 (7/26/2019), Nepal Rasta Bank, Foreign Exchange rate

Source: OAG, 2015 and ADB, 2013

The technical infrastructure is very important when it comes for proper MSWM. In case of KMC, the budget and management facilities for all the elements of MSWM significantly limited. Most of the municipal vehicles and machineries equipment used for collection and transportation of MSW are sponsored by foreign organization which are not well functioning at the moment due to unavailability of spare parts of vehicles and lack of technicians who can fix them in Nepal[8]. Likewise, lack of waste sorting sites, limited transfer station and landfill are the major technical factors for the poor MSWM in KMC. Furthermore, SWM act 2011 stated that municipality would provide separate container to the community to put organic and inorganic waste separately, however, this has not been in practiced in reality (OAG, 2015). Besides this, the insufficient and unmotivated municipal workforces in MSWM activities are also the major challenges for the sustainable MSWM in KMC (OAG, 2015).

The table 3 shows the number of personnel responsible for different activities regarding MSWM in KMC. The number of staff has been declined to 963 in 2018 which includes a large number of sweepers. The decline was due to the retirement of the old staffs and no new staff are hired to replace the vacant positions which added additional burden to rest of the staffs and led to inefficiency in MSWM activities[9].

[8] *Information based on interview with officials from department of environment, KMC.*
[9] *Based information provided by environment department of KMC.*

Table 3: Number of human resource engaged in MSWM in KMC in 2014

Post	Number
Department chief	1
Division Chief	2
Engineer	5
Section Officer	3
Administrative Personnel	36
Junior Engineer	3
Municipal Police	19
Driver	135
Sweeper	828
Other	79
Total	**1111**

Source: OAG, 2015

2.6 MSWM planning in KMC

In 2005 from the support of JICA, KMC had prepared an Action Plan on Solid Waste Management (KMC 2005). However due to inefficient operational activity led to current disorganized waste management system. The action plan need further updates which should include concrete plan, vision, mission and aim for the KMC's effective MSWM. Similarly, recently elected local government representative has to give equal priority to environmental issue such as MSWM as other developmental issues of the municipality.

2.7 Actors involvement in MSWM system in KMC

Different stakeholders such as government body, private sectors, INGOs, NGOs, CBOs and public participate in MSWM activities in KMC. The 32 wards of KMC has a semi-formal MSWM practice that is involvement of private sector in collaboration with KMC. Most of the private organization are informal and are not legally registered to government agency[10]. However, there is also involvement of formal private organization who has an agreement with KMC and NGOs contributed in waste management activities and there is also willingness of community for the waste separation at source (ADB, 2013). In addition, some NGOs and civil society group are undertaking public awareness campaign such as Bagmati river cleanup campaign where public participate to clean river. Likewise, in recent year, some private recycling companies collect waste (paper, plastic, glass bottle, metal and electronic waste) from

[10] *Based on interview with Deputy Director of Environment Management Department, KMC. She also added that government is planning to track all the record of informal organizations and individual who are involving in waste management in KMC. Most of these PSOs has their own monopolized practice on collection and transfer of waste from some wards of KMC. They sort out reusable and recyclable waste and they dump non-recyclable waste in landfill site. However, landfill site is operated and managed by KMC.*

door to door and with free of charge, even allowing public to sell their recyclable waste. Though they are limited to particular area, has contributed in MSWM in KMC.

2.8 Overview on solid waste management policy, law and legislation

According to Hwa 2007, the low level of awareness, lack of technical knowledge, strong policies and legislations, proper plans and strategies for SWM are the major challenges in low income countries in Asia. Likewise, Nepal also did not have the proper policies regarding SWM before 1980s since the solid waste problem was not severe as today in the country. The waste generated in Kathmandu was very low in volume because of less population and fewer industrial activities. These MSW were managed in collaboration with community's people and the municipalities where municipal labour workers called *Kuchikar*[11] were assigned to collect and dispose waste (Pokhrel and Viraraghavan, 2005) however, there was no proper disposal site for these collected waste.

Considering all environment concerns and community hygiene, Nepal government established the 'Solid Waste (Management and Resource Mobilization) Act and Regulations' 1987. This act formed Solid Waste Management and Resource Mobilization Center (SWMRMC) and which is responsible for implementing policy and operate the SWM activities such as collection, transportation, storage, resource recovery and disposal in Kathmandu (Lawcommision.gov.np, n.d. and SWMRMC, 1992). The following figure 13 illustrates the key policies formulated for the SWM in Nepal in different time period.

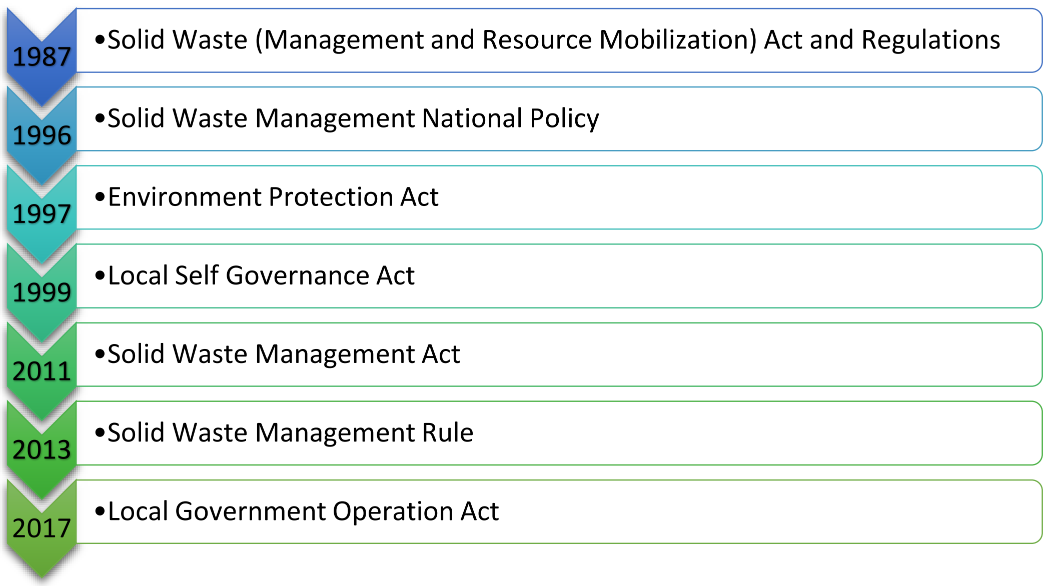

Figure 20: SWM policy and legislation in Nepal in chronological order

Note: Reproduced on the basis of reference from G C, 2018, OAG, 2015 and SJVN Arun-3 Power Development Company Pvt. Ltd., 2019

[11] *Kuchikar are the cleaners or sweepers in Nepali local language and they are generally assigned by municipality to collect and dispose solid waste in Kathmandu in earlier days.*

Similarly, later in 90s, Nepal government enforced national policy on 'Solid Waste Management National Policy' 1996, to deal with the solid waste problem in the country. The main focus of this policy was effective and proper SWM which could help to minimize the environment pollution and impact on human health. Likewise policy aimed to minimize the waste generation, recycle and reuse of waste as resources, increase awareness and public participation and private company involvement for SWM activities for effective management and operation. This policy has 4 main strategies for the proper SWM, which are public participation, source mobilization, technology intervention and privatization (SWM National Policy, 1996).

In 1997, Nepal government had endorsed the 'Environment Protection Act' (EPA), 1997 which emphasized different provision for the SWM. Such as, any institution or individual are not allowed to contaminate the environment that could results the serious impact on people's health and environmental quality.

In 1999, 'Local Self-government Act', 1999 was formulated which highlighted decentralization of responsibility to village development committee and municipalities for operational activities of MSWM within their authority. Municipality and VDC should protect their local environment by encouraging public toward sanitation as well as should organize solid waste collection system, transportation and proper disposal within their surroundings (MoFALD, 1999 and Pathak, 2017).

SWM act, 2011 is detailed which offers the full authority to local government body[12] to take responsibility regarding the implementation of MSWM activities in a proper manner. This act was enforced from 15th June 2011. This act possesses the following provisions (Lawcommision.gov.np, n.d):

- The act also provides authority to local body for the implementation of the different cycles of MSWM such as waste segregation at source, enforce waste management fees, composting and recycling activities and also the proper disposal of waste in the landfill site.
- The hazardous and harmful waste generated from various industries and hospitals should be properly managed by hospital and industries themselves.
- Any private institution or individuals should have license from local government to involve in MSWM activities. Interested private organization shall get license from local government body based on the competition.
- The act encourages the collaboration of local body with private institutions for MSWM and tariff from public for the collection, transport, recovery and disposal of waste.

[12] *The local bodies are the municipalities, sub municipalities and village development committee (VDCs).*

SWM rules 2013 was issued by Nepal government by exercising the power discussed by section 50 of SWM act 2011 which also focuses on waste segregation at source[13].

The Local Government Operation Act, 2017 that has established a robust legal foundation towards institutionalizing legislative, executive and quasi-judiciary practice of the newly-elected local government[14]. Local Government has the core operational responsibilities for the SWM within their jurisdiction.

2.9 Conclusion

It is observed that the urbanization and increasing population has accelerated the MSW volume in which the organic waste is dominating in total MSW composition. This organic waste is landfilled in Sisdol which is critically out of its carrying capacity. Further, it can be analyzed that KMC has poorly managed MSW which is creating environmental and public consequences. Hence, there is an urgent need to manage this MSW problem. For this, following key approaches need to be highlighted for improving SWM in KMC.

i. While the enactment of the new SWM Act in 2011 was a major step toward improving SWM practices in Nepal, it has not been effectively translated into actions and results on the ground. A national SWM policy and strategy that specifies key policy objectives, guiding principles, and an implementation strategy with a timeline and a clear monitoring and evaluation mechanism needs to be developed to provide clear strategic direction to local bodies.

ii. For the effective MSWM, the waste management hierarchy (WMH) can be effective tool. It includes 5 different components which are prevention, reuse, recycling, recovery and disposal (Ec.europa.eu, 2019). The WMH will be helpful to prioritize waste prevention and management. The following figure 21 demonstrate the waste management hierarchy for effective MSWM.

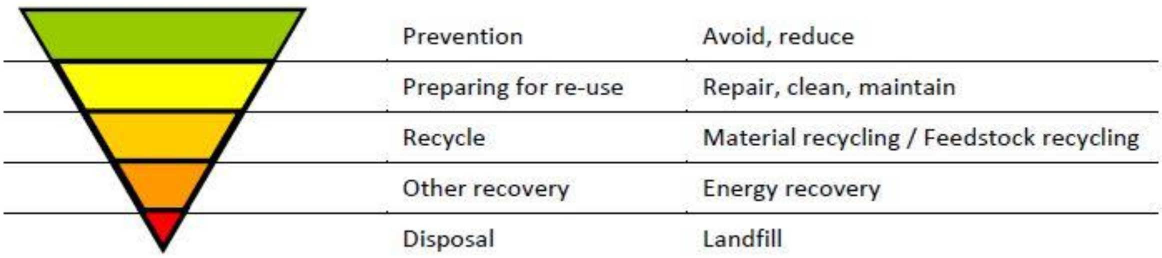

Figure 21: WMH based on the EU directive 2008/98/EC and European commission 2016

iii. Promotion of new concept like Waste to Energy approach should be initiated for energy recovery from waste. In recent years, WtE has been considered as a solution to solve the increasing MSW in many emerging cities and fast growing energy demands (GIZ, 2017).

[13] http://www.lawcommission.gov.np/en/archives/11691

[14] SJVN Arun-3 Power Development Company Pvt. Ltd. (2019). Retrieved from http://nep.sapdc.com.np/page/local-government-operation-act-2074

Chapter 3

This chapter covers the background information on WtE and description of different WtE technologies with its application. Further, it explains the importance of WtE approach as an opportunity for generating energy from MSW in KMC. This chapter also include the calculation of energy that can be generated from different MSW and its analysis. This chapter ends with the description of new proposed MSWM model for KMC.

3.1 Energy recovery

Energy recovery is one of the important components of WMH which is performed by either combustion or anaerobic digestion of MSW and is a most preferred option in term of environment protection. The combustion or digestion of MSW not only support to reduce waste but also recover energy. The generated energy from this process are renewable and it contributes to replace fossil fuel which ultimately reduce GHGs and also minimize the methane generation in landfill site (epa.gov, n.d.).

The heavily increasing MSW in many fast growing cities of low income nations such as Kathmandu has been a part of concerned issue in term of possible impacts toward environment and public health (GIZ, 2017). In this scenario, MSW can be used to recover energy through appropriate WtE technology and by reducing its volume and generating energy. Similarly, it reduces GHGs emission from open dumping and landfill contributing to solve the issue of limited landfill area (GIZ, 2017).

3.2 Waste to energy (WtE) Concept

Pereira and Lee, 2015 stated that there is more challenges than opportunity to manage MSW and get materials from it as recycling products, biogas, heat or energy. MSW composition differs from country to country since its production depend on economic development, climatic condition and cultural and traditional value. The composition of MSW of developing countries is mostly organic while in developed countries the MSW consist high volume of inorganic waste (Trang and Wilson, 2017). The MSW is increasing day by day as the population is increasing, there is an urgent requirement to develop the strategies to manage and treat these growing volume of MSW in the world.

WtE approach and its technologies are favorable for low income countries for converting MSW into useable form of energy (Moya et al., 2017) to deal with the environmental problem and energy crisis. Waste to energy technologies are used as a major tool in the integrated SWM to mitigate the impact of global warming and climate change in most of the developed nations.

WtE is the technological approach that contribute to recover energy into heat, electricity or other substitute fuels such as biogas (GIZ, 2017) from MSW. The scope of the concept WtE is a broad term which includes a wide range of technologies at various scales and intricacies. This technology comprises thermal treatment of waste in incineration plant, co-processing of refuse derived fuel in cement plant or gasification (GIZ, 2017), pyrolysis, collection of methane gas from landfill sites and cooking gas production in household digesters from organic waste (Gumisiriza et al., 2017). These technologies possess different functions and characteristics and can be applied to various categories of waste that include semi-solid (such as thickened sludge from effluent treatment plants) to liquid (such as domestic sewage) and gaseous (such as refinery gases) waste (GIZ, 2017). However, Eurostat 2013, stated that, at least within the European Union, treating MSW is the most common practice[15].

3.3 Waste to energy technology options

WtE technology was started as the incineration technology which was built in Denmark in 1903 for the first time in history (Dbdh.dk, 2019). MSW can be transformed into energy from various WtE conversion processes and most commonly used techniques are thermal treatment technology (thermochemical conversion) and biological treatment technology (biochemical conversion) for converting MSW into energy (Shrestha et al., 2017 and Zafar, 2019). According to Zafar, 2019, thermochemical conversion is applicable for the low moisture content waste whereas biochemical conversion is best option for high moisture content waste such as organic waste. The following flow chart (figure 5) show the various waste converting technologies.

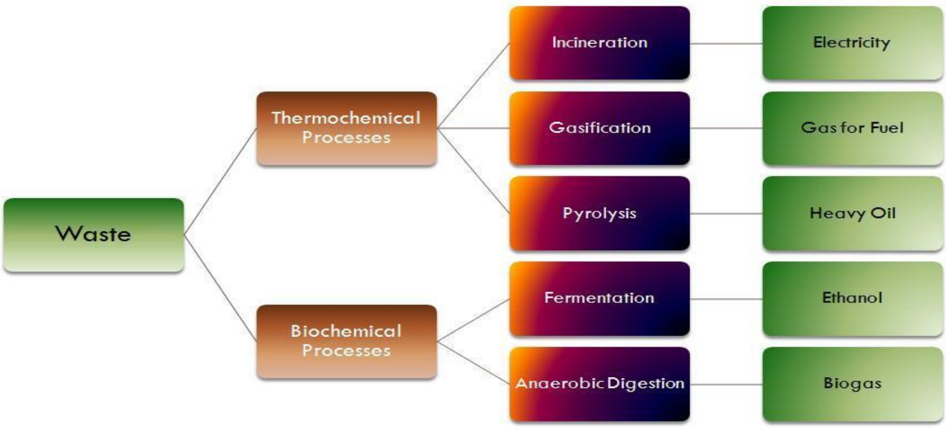

Figure 22: Waste to Energy technologies

Source: Zafar, 2019

[15] https://ec.europa.eu/eurostat/portal/page/portal/waste/introduction/

3.3.1 Thermochemical conversion

The thermochemical conversion can be classified into incineration (combustion in excess air), gasification and pyrolysis. Incineration is the process of combustion of municipal waste in the raw form to generate energy in the form of electricity or heat. The process of combustion takes oxygen to fully oxidize the waste and converted it into carbon dioxide and water producing 850 degree Celsius combustion temperature (DEFRA, 2019). Energy recovery through incineration process is a well-known technique and high quality treatment of municipal waste in big cities which helps to reduce the quantity of the waste to be landfilled. This technology seems feasible for urban setting which is a practical solution to manage huge volume of municipal waste as well as recover energy from it. However, this technology requires high investment since environmental measures should be considered to control emission. Therefore, before implementing incineration technology, waste volume, combustion heat of the waste, location, maintained facilities, operation and maintenance cost and investment has to be deliberated. Furthermore, these environmental consideration and huge investment cost is not preferred alternative in most of the developing countries to implement incineration technology for waste management.

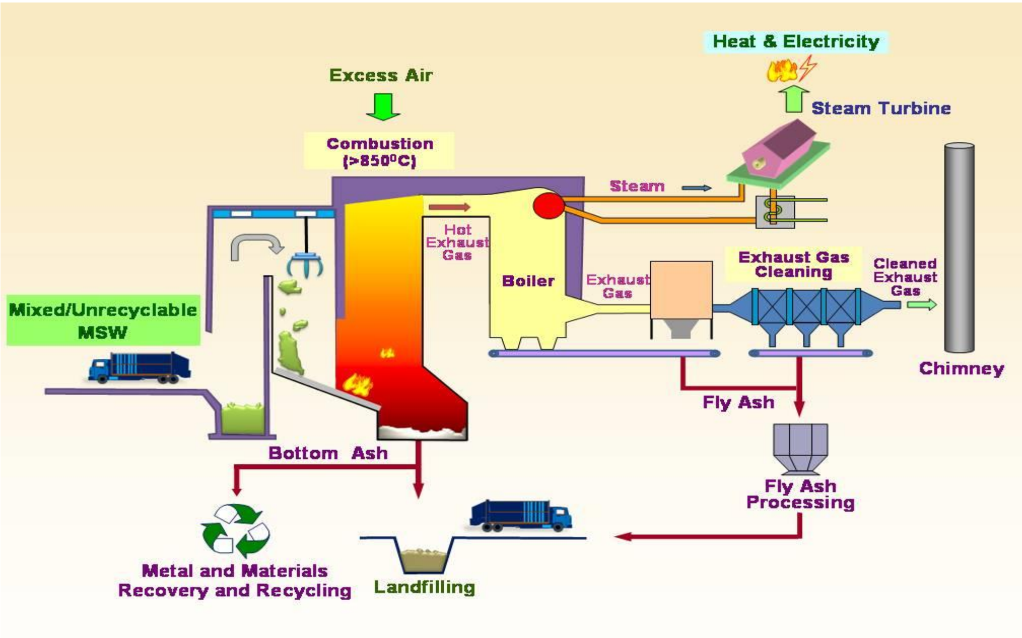

Figure 23: Incineration flow chart which shows the thermal treatment technology

Source: "Problems & Solutions | Environmental Protection Department", 2019

Pyrolysis and gasification technique are used as the alternative to incineration which are thermal treatment process. These process reduce volume of the waste by converting solid waste into gas or oil followed by the combustion. These process are regulated in USA and European Union countries as waste incinerators and these process consist of thermal treatment of solid waste and combustion of resulted gases from process both in site or distributed fuel (Tangri and Wilson, 2017). Particularly, gasification process include decomposition of solid waste requiring high heat which is above 600 degree Celsius in a starved oxygen level (Moustakas and Loizidou, 2010). Likewise, pyrolysis is similar to gasification which also convert waste into oils and gas as well as solid waste outputs in the presence of heat without oxygen supply. These technologies has been testing over 30 years by various companies (Tangri and Wilson, 2017).

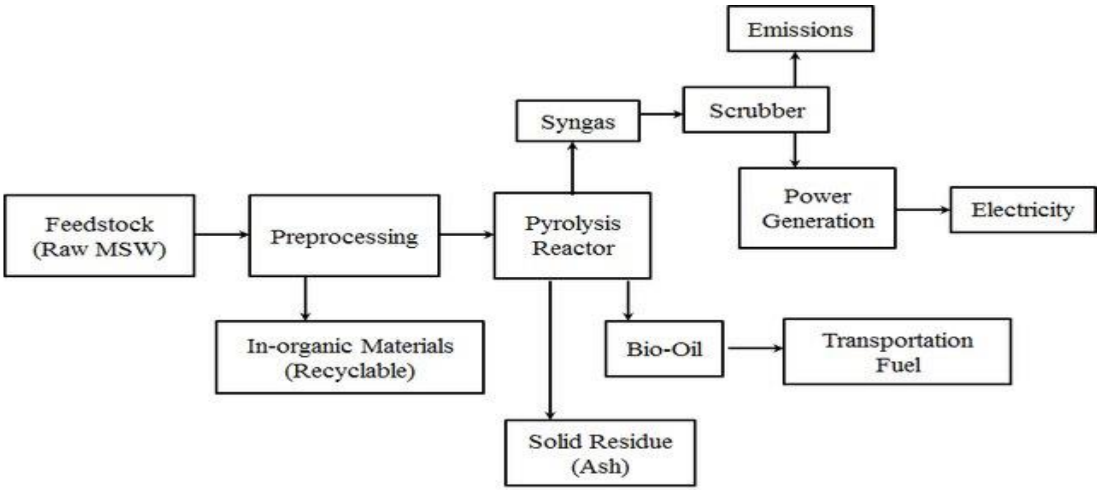

Figure 24: Pyrolysis process flow diagram for municipal solid waste treatment in urban environment

Source: Campos et al., 2015

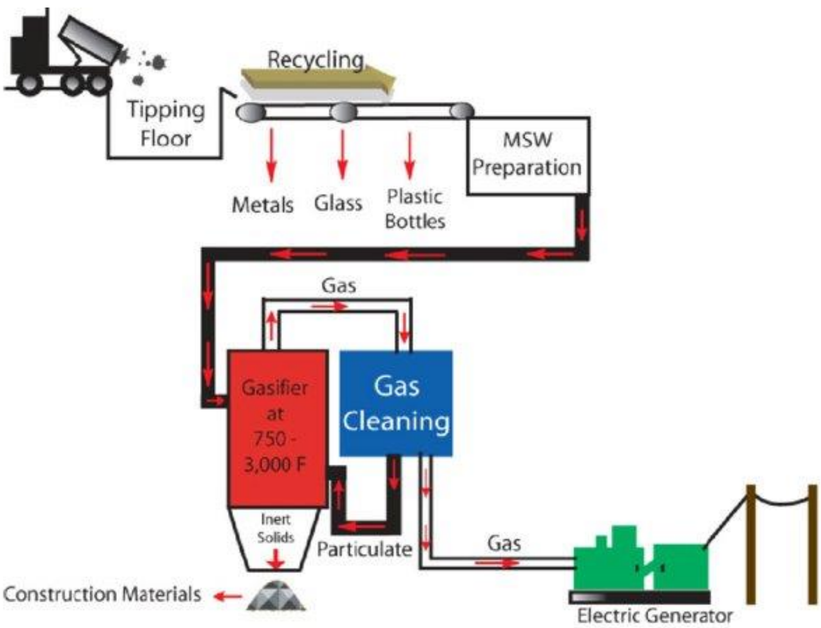

Figure 25: Schematic of MSW gasification and power generation plant

Source: Zafar, 2009

3.3.2 Biochemical treatment

Likewise, biochemical treatment process are done by fermentation (in aerobic condition for composting) and anaerobic digestion (AD) process. AD is a natural biological process of converting organic waste into combustible gas which is a mixture of methane and carbon dioxide without presence of oxygen (Moya, et al, 2017) is also described as WtE approach but is apposite of thermal process. And this treatment process needs limited amount of energy in comparison to aerobic process. AD can be an efficient technology for treating organic waste (Zafar, 2019) since biodegradable municipal waste has huge potential of energy production. Hence, this treatment technology is designed and engineered for the organic MSW to be treated by natural biological process (DEFRA, 2019). AD technology is practical option for managing organic waste in most of developing countries that produce larger volume of organic waste.

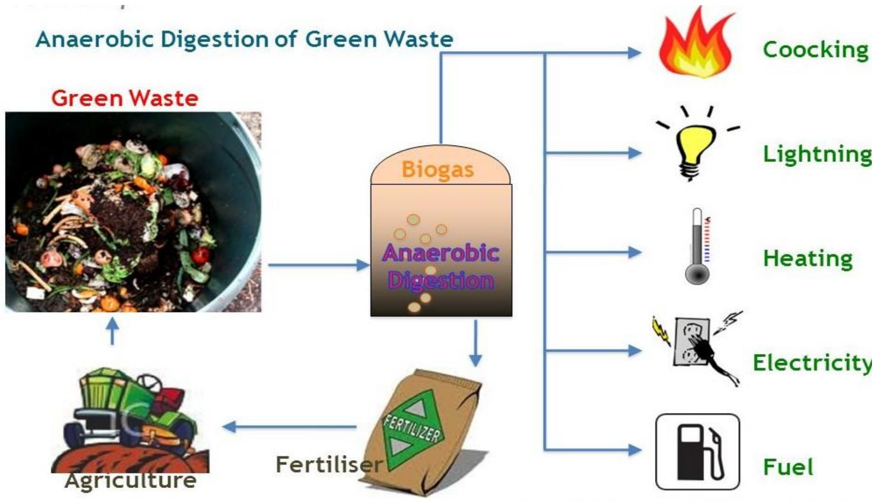

Figure 26: Anaerobic digestion of organic municipal waste

Source: Spuhler, 2010

3.4 Waste to energy: an opportunity for KMC for the MSWM

Nepal is suffering from energy deficit currently. Nepal does not have gas, oil and coal deposits for generating energy. Most of the petroleum product and coals are imported from India where 75% of petroleum products are diesel, kerosene and gasoline (ADB, 2017 and IBN, 2017). Petroleum products share about 12% of the total energy consumption where electricity contributes 2% of nation's energy demand (IBN, 2017).

Furthermore, the fast urbanization and scaling up of economic activities in KMC emerge many issues such as energy crisis and MSWM are most critical to solve as soon as possible (Shrestha et al., 2017). Therefore, the WtE approach can contribute to handle the MSW situation of KMC. The inter-linkage between MSW and energy is clearly visible for the case of KMC, the concept of WtE is still new and unexplored which is considered as unimportant in case of generating energy from it in comparison to hydropower (NPC and IBN, 2014), but has great prospect to tackle both issues.

The approaches and its key advantages of WtE are still not sufficiently noticed for the immediate respond to act mostly in developing countries like Nepal. MSW can be the important resource for generating energy by using WtE technologies even, 3R and preventing waste from generation are most preferred options in waste hierarchy in MSWM system (Shrestha et al., 2014). However, as stated by Idris et al., 2004, it is crucial to assess waste characteristic and its volume before selecting suitable WtE technology both thermal and biological, also it is equally important to analyze energy content of the each waste composition. In addition, as MSW consist of heterogeneous waste materials, investigating energy potential of each waste material is not a simple task to explore.

3.5 Energy content of MSW in KMC

The heat content of each MSW of KMC is calculated theoretically by using given formula on the basis of MSW data released by ADB in 2013. The calculated total heat content of each type of MSW of KMC is presented in table 4 below.

$$\textit{Total Heat Content (E)} = \sum f_i * HV_i$$

Note:

E= theoretical heat content (million Btu/ton)
f_i= Fraction of waste component i in total MSW composition
HV_i = Heat value of waste component i (million btu/ton)
Source: Zaman, 2010

Table 4: Fractional content of MSW composition of KMC and heat value of solid waste composition on dry condition in million Btu/ton and MWh unit (Shrestha et al., 2014)

S.N.	Type of MSW	% of MSW composition	Fraction content of MSW	Heat Value (million Btu/ton)	Heat content in MSW (Million Btu/ton)	Energy content in MSW (MWh)
1	Organic	43.32	0.43	7.6	3.292320	0.960
2	Plastic	21.6	0.22	22.6	4.881600	1.430
3	Paper	25.41	0.25	6.7	1.702470	0.500
4	Glass	2.66	0.03	0.1	0.002660	0.001
5	Metals	1.86	0.02	0.7	0.013020	0.004
6	Textiles	2.77	0.03	13.8	0.382260	0.112
7	Rubber and Leather	0.75	0.01	20.65	0.154875	0.045
	Total value				**10.43**	**3.052**

Note: 1 million Btu/ton=2.9307*10^{-7} MWh

Source for average heat value of different MSW: Shrestha et al., 2014

From the calculation, it is observed that every ton of MSW of KMC has potential to generate 10.43 million Btu of heat that is 3.052 MWh/day of energy can be produced theoretically. Likewise, if organic waste is used to generate energy where other components of MSW can be recycled and reused, nearly 3.3 million Btu of heat that is 0.96 MWh/day of electricity can be generated.

Furthermore, the most essential factor- moisture content of solid waste is very significant to understand the total energy content in the MSW for selecting and implementing appropriate WtE technology (Shrestha et al., 2014 and Sodari & Nakarmi, 2018). The research carried out by Sodari and Nakarmi found that 70% moisture content in organic waste of MSW of KMC where 20% in paper and 5% moisture content in plastic. It is perceived that KMC's MSW composition is dominated by organic, paper and plastic which has high moisture content, however, these waste also has high energy content which is shown in the table. This indicates that the MSW of KMC has comparatively good potential to produce energy by using WtE technology particularly AD for organic waste and incineration for plastic and paper waste.

3.5.1 Electricity generation potential from plastic and paper waste in KMC from incineration

Plastic and paper combined is the second dominant source of MSW in KMC which shares one fourth of total waste. Currently, recyclable plastic and paper waste are exported to India for further processing and remaining from these waste are considered as non-recyclable are landfilled in bulk. Knowing this facts, incineration technology can be adopted to incinerate plastic and paper waste to produce electricity since plastic waste has high heat content.

Therefore, the data from ADB 2013 report is used to calculate energy potential of plastic and paper from incineration technology. The current plastic waste has potential of 1430 kWh of electricity generation capacity while paper waste has 490 kWh theoretically which is shown in table 5. Since the electricity amount is not high but it can contribute during energy deficit period. However, Solid Waste Management Act 2011 of Nepal emphasized on 3 R waste management rather than energy recovery from waste through incineration. Nevertheless, WtE technology as incineration is good option for managing increasing trend of plastic and paper waste in future although current production is not huge as organic waste in KMC. However, burning of plastic waste can produce harmful gases such as dioxin and furans (Verma et al., 2016). Hence the incineration should have pollution control measures to reduce air pollution.

Table 5: Fractional content, heat value, electricity generation of plastic and paper waste in million Btu/ton and MWh.

Type of MSW	% of MSW composition	Fraction content of MSW	Heat Value (million Btu/ton)	Heat content in MSW (Million Btu/ton)	Energy content in MSW (MWh)/day	Energy content in MSW (kWh)
Plastic	21.6	0.22	22.6	4.8816	1.43	1430
Paper	25.41	0.25	6.7	1.70247	0.49	490

3.6 Potentiality of bio-gas generation from organic waste in KMC

It is found that organic fraction of municipal waste is relatively higher than other inorganic waste in KMC where households is the major source and produce 64.24% of organic waste. Analysing this situation, the organic fraction of MSW of KMC can be a great resource for generating renewable energy. Thus, AD as WtE technology is suitable option for converting this organic MSW into biogas (methane) and this can also generate electricity which subsequently reduce the volume of MSW to be landfilled.

AD process is also called as biomethanisation which is the biochemical decomposing of the complex organic material by different microorganisms in the absence of air (Vogeli et al., 2014) to produce biogas. Biogas is an inflammable gas, stable and non-toxic with relatively odorless and colorless character which has heat value of 4500-5000 kcal/m3 when it has methane contain range from 60-70% (Igoni et al., 2008). There are several important parameters which are necessary for the good yield of biogas from organic waste. These parameters are temperature, pH value, feedstock characteristics, carbon to nitrogen ratio (C: N), hydraulic retention time, design of digester and operation situation. Two different temperature is considered as best for the performance of anaerobic bacteria where 30-40 degree Celsius is good for mesophilic bacteria with average is 27 degree Celsius and another is 45-60 degree Celsius for thermophilic bacteria with optimum is 55 degree Celsius (Vogeli et al., 2014). Likewise, ideal range of pH is 6.5-7.5 for the high amount of biogas production (Khalid et al., 2011). Another important parameter for AD process is C: N ratio which influence the biogas production (which will be lower) if its concentration is high in solid waste where best value range is from 16-25 (Vogeli et al., 2014). Likewise hydraulic retention time is the duration of material stays in reactor is another parameter which affects biogas yield and the time ranges from 10 to 40 days (Vogeli et al., 2014). The lesser retention time is rather for higher temperature in the thermophillic range because the process is faster. It also depends on reactor volume that is large volume of reactor needs more retention time to digest organic material and it produces large amount of biogas (Vogeli et al., 2014).

Implementation of AD technology for managing organic waste of KMC requires to considering all these different aspects mentioned as a part of technical factors.

According to Alterative Energy Promotion Center (AEPC, 2014), biogas yield from organic MSW of KMC can be calculated from the following formula.

$$\text{Biogas yield}\left(m^3/\text{kg of VS}\right) = \text{Biogas yield}\left(m^3/\text{kg of VS}\right)*\text{TS }(\%)*\text{VS }(\%)$$

Where, M^3= Cubic metre

TS= Total organic waste

VS= Volatile solid

AEPC 2014 stated that biogas production of 0.35 m^3/kg of VS which comprise of 75% of methane gas and is used for the electricity generation. Further, AEPC suggests in "biogas calculation tool user´s guide" that municipal organic waste contain 20% of total solid (TS) and 80% of volatile solid (VS). That means, it assumes that municipal organic has 80% moisture content in average in Nepal. The biogas and methane gas yield is calculated and presented in table from this data and formula mentioned above.

Table 6: Estimation of biogas and methane production from organic waste of KMC

Amount of organic waste collected for AD (ton/day)	% Total solid (TS)	% of Volatile Solid (VS)	Biogas yield (m^3/kg of VS)	Biogas yield (m^3/kg of waste)	Total biogas yield from organic waste (m^3/year)	Methane gas potential (m^3/year)	Methane gas potential (m^3/day)
202	20	80	0.35	0.056	4,128,880	3,096,660	8,484

Source: ADB, 2013 and AEPC, 2014

The table 6 shows that organic waste of KMC has a potential of generating approximate $4x10^6$ m^3 of biogas which contain approximately $3x10^6$ m^3 of methane (CH^4) per year. That is approximate $11x10^3$, m^3 of biogas and $8x10^3$ m^3 of methane gas can be generated every day from the organic waste of KMC. Likewise, the produced methane can be used to power the electricity generator. This noticeably indicates that organic waste can play vital role in energy demand, reduce landfill waste and produce nutrient rich organic fertilizer as digested material which can improve the quality of soil for the good crop production (US, EPA, 2018).

3.6.1 Biogas to electricity

There are various type of technologies employed for biogas power generation such as fuel cell, Stirling engines, diesel engine, gas motors with spark ignition, gas turbine, combine heat and power system (CHP). Biogas can be directly converted into electricity by using fuel cell theoretically. But for this, extra clean gas and high priced fuel cells are needed. Therefore, using of gas motor turbine with spark ignition in a diesel engine system can be used for the conversion of biogas to electric power since biogas has high knock resistance and can be used in motor combustion with high compression rates (Energypedia, 2019). Thus, this can be implemented for biogas power generation from MSW of KMC. In addition, biogas should ensure its quality before using for different application. Since biogas also contains not only methane (CH_4) but also components as impurities such as droplets, air, hydrogen sulphide (H_2S), and carbon dioxide (CO_2) (Kipyegon, 2006). Hence, these components should be removed for its further utilization. The removal of these various gases can be taken place in a stepwise process (Vogeli et al., 2014).

The following schematic diagram figure 27 shows the AD process to generate biogas and electricity.

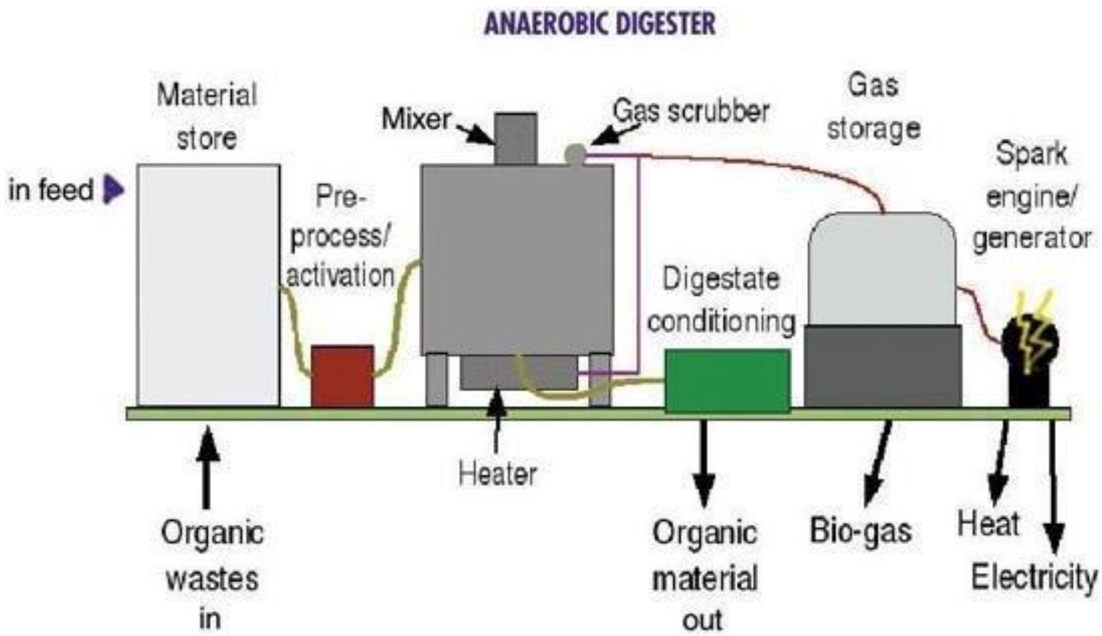

Figure 27: Anaerobic digestion process and electricity generation from biogas

Source: Beemaraj &Prasath, 2013

Calculation of electricity generation from biogas

The average calorific value of biogas is 21-23.5 MJ/m^3 which has an electricity generation potential 6kWh/m^3 when using gas motor as combustion engine (Agency of Renewable Resources, 2005, AQPER, 2019). Biogas contain 75% of methane gas produce from organic MSW (AEPC, 2014).

Formula for calculating electricity from Methane gas

Electricity generation (MW/day) = (methane yield/day*energy generation/m^3)/ (75*1000*24)

Source: (Adhikari, Khanal & Miyan, 2015)

Table 7: Estimation of electricity generation from methane from the biodegradation of organic waste of KMC.

Estimated methane (m^3/day)	Energy generation per m^3 (kwh)	% of average methane in biogas	Electricity generation(MWh)/day
8,484	6	75	2.83

The electricity generation from AD process is illustrated in table 7. About 2.8 MWh/day of electricity can be generated from the methane gas produce from the anaerobic digestion of organic waste of each day of KMC. Hence AD can be the promising technology for managing organic waste of KMC and help for recovering energy crisis and help to reduce dependency on import of external fuel for cooking.

In addition, the dumping of huge amount of organic waste in landfill can be reduced significantly and minimize the release of several gases such as methane, carbon dioxide in the environment which ultimately contribute to global warming lead to climate change and discharge of leachate causing water contamination from the landfill waste.

3.7 WtE technology integration in MSWM framework for KMC

The following framework presented in figure 28 developed by the researcher after the in-depth analysis of current MSWM which is proposed for the sustainable MSWM system in KMC. This framework is prepared with considering various factors with particular focus on KMC. This framework consists of different elements of MSWM which is more systematic and more sustainable way of managing MSW with considering environment and public health which follows the waste hierarchy concept and sustainable integrated MSWM. In addition, WtE approach is particularly focused as it is the efficient way to reduce the volume of waste sent to landfill and it generates useful energy. Hence, WtE approach can address the energy demand issue and contribute in sustainable MSWM as well.

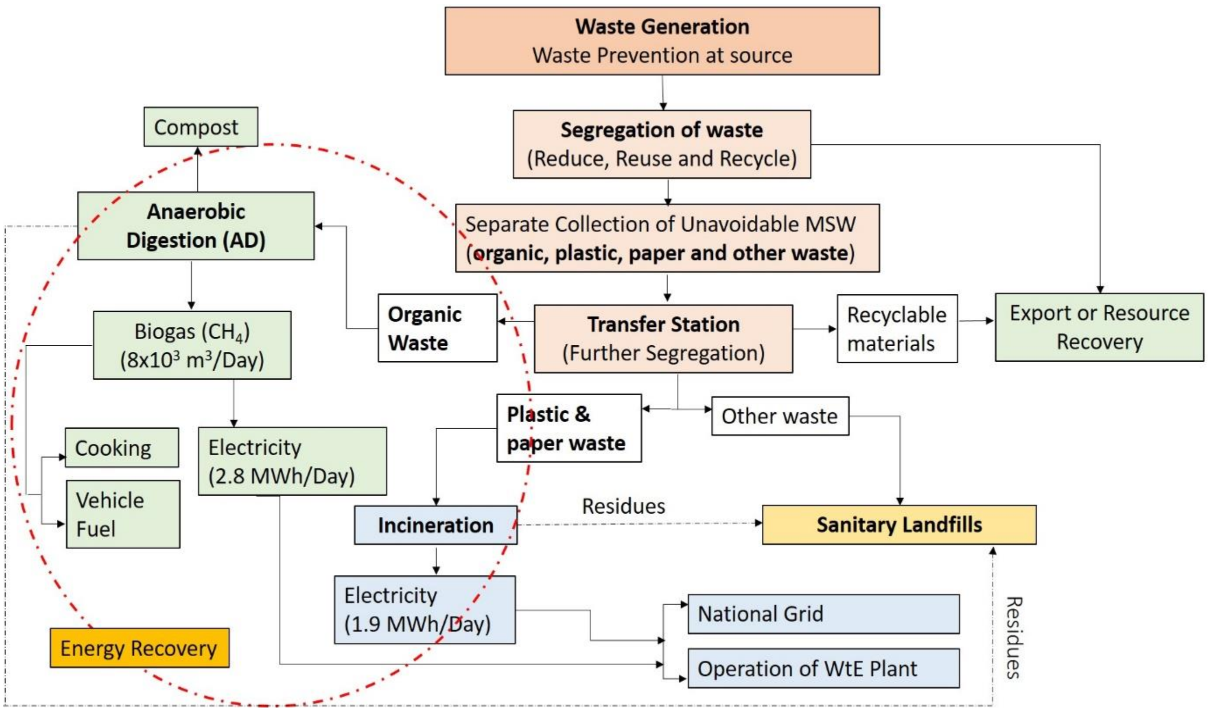

Figure 28: The proposed MSWM framework for Kathmandu Metropolitan City

3.10 Conclusion

The presented issue of current unsystematic MSWM of KMC cannot be overlooked. For this, the proposed MSWM framework for KMC can be the solution to address the MSWM problem. The proposed framework is systematic, efficient and more sustainable MSWM than the current system in term of its long term benefits and is more environment friendly system. This framework is focused on energy recovery using WtE technology as one the efficient way for managing waste and generating energy. However, different aspects such as proper policy, public awareness and organizational arrangement, financial and technical factor are inevitable to be considered for transforming current MSWM system to more sustainable MSWM for KMC. Following are the factors which can influence the establishment and integration of WtE technology in MSWM for KMC:

- It is observed that KMC's MSWM system lacks organized policies and legal framework. Hence, an appropriate legal framework need to be established and its execution has to be in process of development before implementation and operation of any WtE plant in MSWM system.
- Public awareness is major requirement because, the proposed framework demands the waste segregation at source as an important element.
- The most important aspect, an institutional arrangement should be adequately effective and strong for implementing sustainable MSW.
- For the decision making, cost benefit analysis and assessment on understanding of WtE technology operation is very important since this technology are relatively expensive.
- Likewise, technical human resource is also required for establishing WtE system.

Chapter 4

This chapter covers the comparative analysis of existing MSWM system and newly designed MSWM framework in chapter 3. Hence, this chapter presents analysis of the different aspects need to be changed for implementing the proposed framework for the systematic MSWM in KMC.

4.1 Requirements for integrating WtE system in MSWM of KMC

Some basic conditions has to be met before implementing appropriate WtE technology in MSWM system in KMC. Likewise, various aspects need to be adjusted and changed for the implementation of proposed framework which are discussed below.

4.1.1 Management aspect

The following figure 29 shows the differences between the current MSWM system which is traditional waste management hierarchy and the proposed framework for sustainable MSWM as new waste management paradigm. The proposed framework is more focused on waste reduction and energy recovery. GIZ states that WtE technology should be viewed as a part of sustainable MSWM system where waste prevention, reduction and recycling options has high preference (GIZ, 2017).

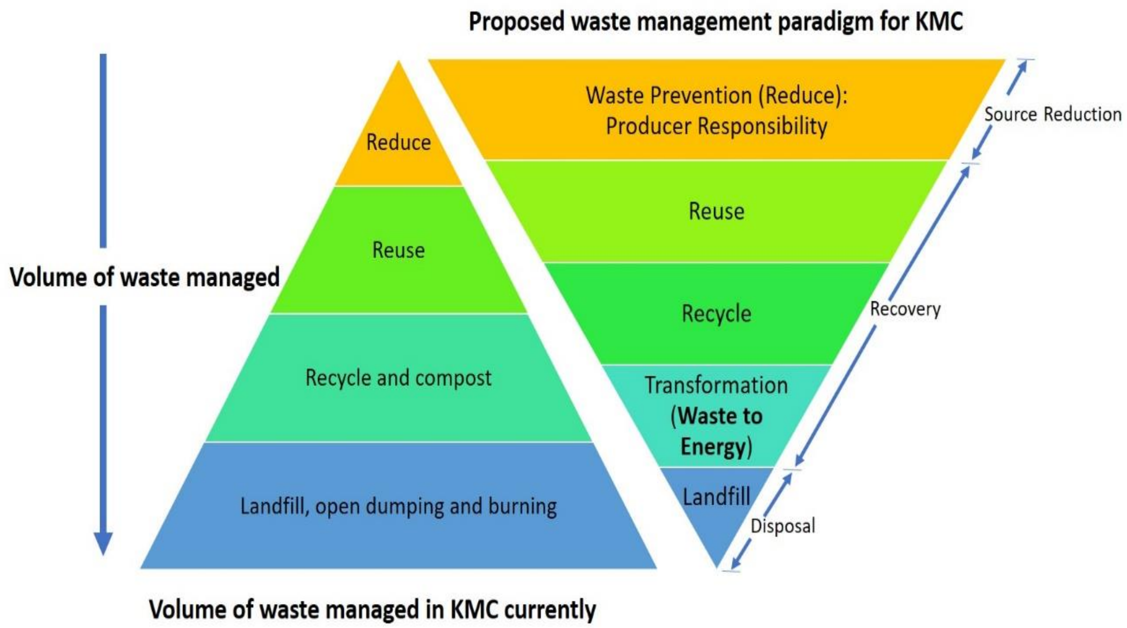

Figure 29: Comparison between current MSWM and proposed framework for sustainable MSWM based on waste management hierarchy in KMC

Note: Reproduced WMH for KMC based on reference from (Fagariba & Song, 2016).

The existing state of MSWM is ineffective and unsystematic because of lack of technical and financial capabilities of KMC and many factors related to MSWM. Therefore, various aspects regarding MSWM are very essential to be reflected for proposing to implement sustainable MSWM framework.

Improvements toward sustainable SWM

Current ineffective practices need to be stopped first. For example, collecting waste in open piles on the roadside, which is done by KMC, is not only inefficient but highly unhygienic, creating a public nuisance and health risks. The present scenario of MSWM involve waste generation-collection-disposal in very irregular manner. It does not have any strategic directive for systematic operation of day to day activities of MSWM. In addition, waste are collected in bulk without any segregation since municipality has not announced any system or methods for segregation of waste at source which could have motivate citizen to participate in sustainable MSWM (OAG, 2015). In the present scenario, KMC is accountable for every activities regarding MSWM from waste collection to final disposal without guiding concrete framework. As a result, KMC is facing challenge of chaotic MSWM system. The Office of Auditor General analysed in the study suggested that KMC does not have sufficient human, technical and financial resources and unable to coordinate with different sectors for performing successful MSWM system (OAG 2015). Therefore, for improving this situation, technical and financial aspect are another essential elements that should be carefully assessed.

4.1.2 Approach for implementing proposed framework of MSWM system in KMC

The present MSWM system basically focused on MSW collection and disposal. The existing policy regarding the SWM system lacks the proper and specific guidelines required for the sustainable MSWM. Likewise the policies are rarely implemented which resulted the current mismanagement of MSW in KMC. Therefore, the changes and amendment in current policy and its implementation are required for sustainable MSWM in KMC which are further discussed below.

i. MSW generation

Sustainable MSWM always associated with 3R approaches (reduce, recycle and reuse) in waste management which is also emphasized in SWM act in Nepal. However, it is not in practice at present. Hence, this proposed framework recommend less waste generation at source which means it contributes in waste minimization at source. The generated waste disposal in roadside, riverside and open space should be stopped and different waste bin should be provided to each neighborhood for discarding different waste and collection of this waste should be carried out regularly.

ii. Segregation of organic, plastic and paper waste at source

Segregation is one of the key elements of MSWM in term of waste recovery and processing that is to give second life to waste in a circular manner. Hence, this framework suggests the segregation of waste into organic, plastic, paper and other waste at source. Therefore, the policy should incorporate this issue through public awareness program and school level curriculum. In addition, KMC should provide incentives to encourage public to involve in sustainable MSWM such as by providing different bins for different waste.

iii. Collection of different segregated waste

The collection is another important element which involves not only the collection of waste (organic, plastic and paper) from different sources but also the transportation of these waste to the specific transfer station. For effective collection, the collection of different waste should be done on different day. For example, biodegradable, non-biodegradable (plastic and paper) waste and other waste can be collected in different day that ensure the efficiency and importance of segregation. The policy should address this issue and properly indicate that there should be provision of penalty for those who does not follow the rule.

iv. Transfer station and transport

The allocation of proper transfer station for storing of waste collected from KMC is essential because the waste need to be sort out further before transferring to processing plant and landfill site. The transfer station either located near to processing plant area or particular planned area. After sorting of all waste transfer to processing plant to convert waste into energy and remaining refuse waste to sanitary landfill.

v. *Energy/resource recovery and processing*

The existing policy mentioned modern technology for managing and recovering waste to be implemented, however, it does not provide specific directive for its implementation. Hence, the policy needs to be adjusted and it should incorporate the innovative technology like WtE.

The larger share of organic waste generated in KMC can be managed by converting waste into biogas through WtE technology (anaerobic digestion process). Likewise, plastic is the second highest amount in MSW composition of KMC and has high energy content. Hence, plastic waste can be managed by incineration which also produce energy. About 90% MSW can be recovered from WtE system in KMC. 43% of organic waste can generate $3x10^6$ m^3/year of methane gas and 1033 MWh/year of electricity theoretically. Likewise, incineration of about 22% plastic and 25% paper waste can produce 700 MWh/year electricity in KMC. This can play important role as alternative energy source in meeting energy demand.

vi. Final disposal

The least prefer option in waste management hierarchy is landfilling of waste. In case of MSW of KMC after implementation of proposed MSWM framework, only about 10% of remaining waste consisting glass, metal, rubber and leather that can be further segregated for recycling excluding nearly about 2% inert waste (non-recyclable, non-reusable and non-recoverable) and residues coming from bio digestion process and incineration process can be landfilled. If 90% of waste recovered through the proper implementation of WtE technology as discussed above, about 419 tons of waste can be reduced and about 47 tons waste has to be landfilled as final disposal. The study carried out by ADB in 2013 also reveals that only about 10% of MSW of KMC has to landfill if waste resource recovery method is maximized.

Regarding the site for the waste disposal in future, Nepal government has already bought land in 2007 at Banchare Danda in Nuwakot district which is 28 km from the centre of KMC. This site has been proposed for developing proper sanitary landfill site. This location can be the ideal site for establishing WtE infrastructure and also transfer station since allocated area cover adequate land (402,922 sq.ft) (KMC, 2018). Therefore, the most important element, the land for waste treatment, processing and disposal is already confirmed. However, the project has not been commenced until now. Hence the proper plan and strategic framework is needed with strict implementation and enforcement within time frame.

4.1.3 Policies and legal framework

When establishing a proper MSWM system, a robust framework is needed which ensures the achievement of the implementation. Hence, the appropriate legal framework ensures the specific needs to be addressed and procedures to execute them. In case of KMC, this aspect stands as the most key aspect to be addressed (Dangi, 2009) since, the existing policies are not ensuring all the issues related to MSWM. It can be analyzed that though existing regulations and policy represent the progressive steps for the sustainable MSWM system in Nepal. However, these policies have not been translated into action (Dangi, 2009). Hence, for the implementation of the proposed framework for MSWM through newly elected local government on the basis of Local Government Operation Act 2017 in KMC, the following points has to be addressed.

- The policy need to be amended with clear and strong directives for the improvement of current MSWM.
- The clear and achievable targets, guiding strategies, and implementation plans with realistic schedule are the major elements to be considered for the successful implementation of MSWM system in KMC.
- Likewise, the KMC takes almost entire responsibility for the overall MSWM activities but unable to track information. Therefore, it is important to establish a criteria of performance evaluation and monitoring body to take action.
- The SMW Act 2011 encourage the involvement of private sector in MSWM after obtaining proper license from government. However, there are various private sector organization working informally in MSWM activities without license at present. Further, there is no proper logical plan for overall MSWM activities. Hence, it is very difficult to track information on MSWM activities.

- Furthermore, the MSWM system lacks clear vision, mission and goals that led KMC to carry out MSWM activities in unplanned and ad-hoc basis which witnessed the chaotic MSWM since many years (OAG, 2015).
- The well designed strategic plan and programme that can provide a systematic MSWM framework directive.
- Likewise, regulatory instrument such as environmental law and policy should be considered before planning of MSWM system since MSWM is multi aspect issue.
- Most importantly, legal framework should include the provision of commercializing the generated alternative energy. For instance, right to sell energy in local level or connect to grid that will encourage private sector to involve in WtE technology approach.

4.1.4 Financial aspects in term of establishing WtE plants in MSWM system

Implementing WtE plants require considerably high investments in comparison to sanitary landfill. The investment cost includes not only treatment procedure but also include operation and maintenance cost along with cost allocation for operational risks such as accident or fires. Thus, securing funding for implementing sustainable MSWM is quite challenging for the municipality, thus it is suggested that PPP approach can contribute in this regard where private company can invest for establishing and operating WtE facilities in collaboration with government. National subsidies provision can contribute in initial phase of implementation. In addition, fund can be managed by collecting waste management charge from public and revenues from selling of recovered energy (biogas and electricity) and compost. Further, access to revenue from international carbon fund such as green climate fund and tax refund for promoting clean energy can be another source of fund for the regular operation of the facility.

4.1.5 Technical aspect

According to Solid Waste Management Act 2011 of Nepal, municipalities are accountable for all the activities of MSWM from infrastructure development and its operation of every particular infrastructure such as transfer station, processing and treatment plant, biogas plant, landfill, collection from source, transport and to final disposal of MSW within their territory. However, due to lack of technical capacity within KMC, access to appropriate technology and its understanding are the major constraints which has restricted KMC to meet these responsibilities mentioned in MSW act. Likewise, lack of research and survey on MSW are another technical issue in KMC that has limited development of plans and strategies for the proper MSWM system. Hence, regular monitoring, survey and research on waste generation, composition, volume, and overall MSWM activities should be carried out annually.

WtE technology has not been widely used in Nepal. However, small scale biogas in household level from animal manure in rural area was initiated. This initiation was very effective in reducing firewood consumption. The Netherlands Development Organisation (SNV) started the biogas support programme (BSP) in 1992 for the promotion and development of biogas and it was funded by the Netherlands Directorate-General for International Cooperation (DGIS) (Mendis and Nes, 1999). Since then, there are around 0.3 million biogas plants has been installed all over Nepal which has capacity of 2, 4, 6 and 8 cubic metre (AEPC, 2019). This biogas is used for cooking purpose and residue are used as soil fertilizer. This technology is adopted from outside while the digesters are built in Nepal with local materials.

However, in the case of implementing WtE system in large scale in KMC, the existing knowledge is not sufficient. Hence, the technical knowledge can be adopted from outside, for instance European countries and for infrastructure establishment, India can be the option since small scale industries are importing required equipment for installing biogas from India.

4.1.6 Public participation and consultation

Municipality solely cannot perform and meet all the activities related to MSWM and its issues of maintaining hygiene and sanitation of municipality. Community are the foremost in case of MSWM since they are generating waste. Thus, their participation in MSWM is important. The new framework encourage community participation as an important stakeholder for MSWM. The new working procedure should focus on the current environmentally harmful practice and should not repeat again. Such as waste accumulation in open public spaces. For this, private partner should promote source separation at source and keep different waste in different waste bin in public places as well as at household level and more emphasis should be given to 3R waste management practice. This awareness should begin from very basic, for instance 'no littering' in public places. Likewise, there should be rules for collecting different waste in different day, for example, collection of organic waste in one day and inorganic waste in another day. And this rule should be strong with some penalty provision such as household who do not follow rule would get fine or waste won't be collected.

4.1.7 Public private partnership (PPP)

It has been realized that municipality office only cannot handle all the activities related to MSWM. The efficient MSWM can be undertaken through the private public partnership approach. Traditionally, it is understood that municipalities are distinctly accountable for overall MSWM in Nepal (World Bank, 2016). Hence, formal involvement of private sector is rarely seen and has not possessed impressive results at the present situation in KMC. However, the PPP approach is evolving in many developing countries for the efficient MSWM. Thus, the PPP approach has a great potential for improving the overall operation and management in collection, transportation, processing and final disposal of MSW with very cost-effective manner (ADB, 2013).

The suggested framework for MSWM requires PPP approach since the current context of MSWM system is incapable of efficient operation of whole MSWM supply chain. However, the municipality should be able to select qualified and experienced partners with complete strategic operation plan. Hence, municipality should enhance its capacity to formulate strong policy under sustainable MSWM based upon PPP approach. In addition, it is required to strengthen the municipality capacity in term of conducting competitive bidding (ADB, 2013) and develop the robust system for monitoring and evaluation of overall MSWM activities through private partner. The private partner is suggested to take overall responsibility for managing entire supply chain of MSW under the government norm and regulations.

4.1.8 Data management, updating, and dissemination

Data on municipal waste is very essential for developing strategy and plan to design efficient MSWM in any municipality. However, there is no adequate data collection system and is seldom updated in KMC in current situation. There is lack of study on MSWM due to lack of information and data on MSW generation, its composition. As a result, it is difficult to develop plan for designing proper MSWM system.

Therefore, it is suggested that the data related to MSW activities should be regularly tracked, updated and disseminated to related stakeholders. This will help the stakeholder including public to understand the overall MSWM status and enable to compare the situation over the time which ensure to make plan for further improvement. And the tracked data can be used by research scientists and academicians for further research to innovate new prospective in MSWM.

4.2 Conclusion

The prepared sustainable MSWM framework based on present circumstances requires PPP approach with commitment in cooperation with citizen since they are primary source of waste. This system encourage to prevent and reduce waste at the source and is basically grounded on waste hierarchy. In addition, the existing policy need to be amended as discussed above for the smooth implementation. All these aspects will contribute to establish the recommended framework for MSWM in KMC which is the dream of citizen of Kathmandu. Most importantly, the implementation of this framework for MSWM can generate various benefits which are discussed in appendix 4.

Chapter 5

This chapter will make the conclusion of this research which mainly answers the main and sub questions of this research. The chapter ends with recommendation and overall reflection of this study.

5.1 Conclusion

The current MSWM system of KMC is completely unsystematic and traditionally practiced. KMC is accountable for carrying out MSWM in which the department of environment is responsible for every activities related to MSWM. However, informal sector are very active in collecting, abstracting some material for recycling and transporting waste to dump in landfill site. Surprisingly, most of these organizations are not registered legally and it is hard to track all the information and data related to MSW. Likewise, the important stakeholders directly and indirectly involved in MSWM of KMC are Government of Nepal, municipality office, SWMTSC and other line ministries.

The 3 R concept to manage waste at source has not been practiced and source segregation is negligible. Households, commercial, institutions and industries are the main source of MSW generation in KMC where organic waste share large fraction of total MSW and is followed by paper and plastic. The inorganic waste can be either recycled or reused. The generated waste are collected from door to door, limited public container, roadside and other public places by KMC and informal PSOs. KMC is collecting from 12 wards and informal sector collecting waste from 20 wards of KMC. The collected waste are completely mixed. Hence, bulk amount of unsegregated waste are transferred to landfill and informal workers such as waste pickers and scavengers separate recyclable and reusable waste by hand. These recyclable and reusable waste are sold in local scrap dealers and export to local recycling industries or to India for further process. The remaining waste including all organic waste which is about 44% of total MSW are landfilled in Sisdol. This is only the landfill for disposing waste of whole Kathmandu Valley and already reaching out of its carrying capacity. The concept of resource recovery from waste is totally absent in current MSWM system to reduce the volume of MSW and generate energy. In addition, the present MSWM system doesn't meet the environment standard which is causing severe impact in environment and human health.

Thus, MSWM issue appeared in a critical situation which can be solved with an applicable solution. For this, KMC should follow the systematic and appropriate framework for MSWM which should integrate various approaches such as WtE technology and using waste management hierarchy guideline.

A framework developed by the researcher after the in-depth analysis of current MSWM in KMC which is proposed for the sustainable MSWM system. For instance, the proposed framework in this research can play an important role for the effective and sustainable MSWM that helps to protect environment in KMC. This framework is particularly focused on waste segregation at source and energy recovery using WtE technology for effective managing waste. The generated energy will contribute to fill the gap of energy demand for increasing population in Kathmandu. Two type of WtE technology has been proposed after the MSW generation and composition analysis which is AD for municipal organic waste and incineration for plastic and paper waste. Anaerobic digestion of organic waste can generate approximately $8x10^3$ m^3 of methane (CH^4) gas per day which can be utilized for cooking purpose since citizen of KMC are dependent entirely on imported LPG from India. Likewise, about 2.8 MWh/day of electricity can be generated from methane gas. Furthermore, incineration of plastic and paper waste can produce about 1.9 MWh/day of electricity in total which is not much, however, can contribute in continuous growing energy demand in KMC. In other hand, about 419 tons of MSW (about 90% of MSW of KMC) can be reduced if these WtE technologies will be implemented. Only about 10% of non-recyclable waste and residues can go to landfill.

For implementing the proposed framework of MSWM system in KMC, different aspects should be considered. Such as PPP approach in collaboration with government and the private sector is the first thing to be adopted for systematic MSWM. The knowledge sharing for the public awareness and dissemination of information about the MSWM system and its significance are essential to be conducted simultaneously to the citizens. This system should encourage people to segregate waste at source. Most importantly, the existing policy need to be amended and also the KMC should formulate precise and strict policy and guideline for MSWM. These aspects will contribute to create “Clean and Green Kathmandu” which is the dream of citizen of Kathmandu.

5.2 Recommendation

This section provides the recommendation for the best MSWM system in KMC which is very specific and based on this study finding. After the assessment and analysis of current MSWM practice, its impact in environment and public health, the potential solution and changes needed on present system to deal with these issues are discussed in prior sections. Based on this, the following recommendations are made.

A new framework for MSWM in KMC

Systematic MSWM framework is developed which is centered on sustainability and waste management hierarchy after the investigation of current inefficiency in entire MSWM supply chain. This framework requires PPP approach for implementation for improving the effectiveness in management since the current system is implemented by KMC but very poorly operated. For involving PPP approach, the existing SMW policy need to be revised and KMC should also formulate a specific policy including the details about the collaboration with different stakeholders.

The proposed model for MSWM starts with 3 R principle of waste management hierarchy that is waste being reduced at source and it prefers reuse, recycle and recover in the whole waste management chain which are the essential components to reduce waste and only less waste has to be landfilled ultimately avoid extra cost for final disposal and minimize the environment risk.

Then the waste separation at source is also a high priority in the framework that will subsequently contribute in smooth MSWM as it saves time and cost for further segregation. The separated waste then transported to waste recovery facilities (WtE) plants which can be established near to landfill (the new landfill site 'Banchare Danda' allocated by government). As KMC is generating large fraction of organic waste, AD as a WtE technology is mentioned in the framework to generate energy. Though, the concept WtE is yet noble and unexplored in Nepal but this can be the practical solution for minimizing waste and generate energy in the same time can support energy demand. The generated energy can be used as vehicle fuel, cooking gas and to generate electricity.

As PPP approach is suggested to hold responsibility of MSWM activities, the public awareness programme on MSWM and its importance should be conducted through media and workshop which should also stand in top priority in the framework. Similarly, distribution of different waste bins in public area should be installed. This can help to stop littering in public and open space.

Further research

Further research are urgently needed to investigate the other issues such as medical waste management, construction of new landfill site in Banchare Danda related to MSWM. The lack of availability of data and information regarding MSWM in KMC is the limitation of this study. . Hence, it is strongly recommended to KMC office and academic institution to conduct research, collect data on timely manner and update them. The available data are mostly unreliable and insufficient. This might hinder for developing proper plan and strategies regarding MSWM.

5.3 Overall reflection of this study

Municipal waste management has appeared as one of the major challenges in KMC for many years since the Sisdol landfill has been out of its capacity to accommodate increasing waste of Kathmandu. In addition, waste dumping in open public spaces has been creating not only nuisance in the environment but also impacting public health by spreading diseases by various vermin and insects. The current MSWM system lacks proper framework that should help in addressing every aspects regarding MSWM. The current MSWM system lacks proper framework that should help in addressing every aspects regarding MSWM. Although government has formulated policy in different time period aiming for the proper MSWM however, it is found that enforcement provision for strict implementation does not exist until now. The different activities related to proper MSWM such as waste segregation at source and energy recovery which are mentioned as most important aspects to be executed, however, these are limited only in policy documents.

Similarly, it is observed that KMC lacks motivated and proper technical staff to handle the overall MSWM system. In addition, the attitude of citizen towards MSWM need to change. It is also noticed that waste is taken as nuisance and citizen perceive that managing municipal waste is only the responsibility of municipality. The people's perception towards MSWM require to change and they should recognize this issue and participate and cooperate municipality in MSWM, for instance, in waste segregation at source.

After assessing and investigating the current MSWM and different aspect related to MSWM in KMC, it is distinctly noticed that disorganized MSWM system is currently in practice and waste are discarded in landfill without resource recovery which urgently needs to change for the proper MSWM.

Therefore, this research emphasized on integration of WtE technology in MSWM system for recovering and reduce waste that goes to landfill. For this, planned and strategic framework is required which is developed as proposed MSWM model for KMC. This framework highlights mainly to recover energy from waste that helps to reduce waste and contribute towards environmental protection. The implementation of this framework requires to update major aspects such as policy and legal framework, managerial aspect, financial aspect, technical aspect and adoption of PPP approach. The proposed model can be an example for the MSWM in many other municipalities of Nepal as many municipalities are emerging as big cities and are facing MSWM challenge.

Most of the municipality rarely have proper plan and strategies for proper MSWM system. Hence, the developed framework and knowledge (different theories and approach used such as waste management hierarchy and WtE approach) in this study can contribute in developing plan for MSWM.

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Appendix

Appendix 1: Data and information required for the research and accessing method for answering the research main questions and sub questions

Research questions		Data and information to answer the research questions	Sources of data	Accessing data
Main question	Main question: How is the waste management system in Kathmandu Metropolitan city currently organized and managed and which changes are needed to use the waste as resource for energy production?	Demography and socioeconomic situation of Kathmandu metropolitan city History of the solid waste management in the metropolitan city and observation Policy on solid waste management Type of current waste management practice in the metropolitan city Impact of current waste management practice (environmental and social)	Secondary Data and different literatures, reports, journal, central bureau of statistic, policy documents	Content analysis Search method for different literature
Sub questions	Sub question How is the current waste management system in Kathmandu Metropolitan City organized with what results?	Waste collection, transport, treatment and dumping processes Type, composition and volume of waste generated in the metropolitan city Organization /stakeholder working on waste management Any private sector's involvement in the solid waste management	Primary and secondary data Primary information from interview for qualitative analysis Secondary data and different literatures, reports, journal	Content analysis Face to face interview to access information from officials
	How could a waste management system according to concept of waste to energy look like for KMC?	Available policy documents Type of technology (converting waste to energy) and its feasibility in context of type of waste generated in Kathmandu Different literature analysis (from other country who has practiced waste to energy approaches)	Primary and secondary data and different literatures, reports, journal Primary information from interview for qualitative analysis Reports and documents	Content analysis and search method for different literature Face to face interview to access information from officials
	What changes in the current waste management system of Kathmandu are needed for transforming it into a waste to energy system?	Municipality's plan for applying waste to energy concept to manage solid waste Type technologies that municipality are willing to implement Policy gap for effective waste management plan Different literature analysis (from other country who has practiced waste to energy approaches)	Primary and secondary data and different literatures, reports, journal Informant: from municipality and AEPC for secondary source validation Available planning documents and related stakeholders	Content analysis and search method for different literature Content analysis and interview with official from municipality and AEPC

Appendix 2: Allocation of budget for different SWM activities and expenses in KMC

Category of expenses	2013/14		2012/13		2011/12	
	Budget	Expenses	Budget	Expenses	Budget	Expenses
Salary and other facilities of sanitation personnel	290000	279463	254100	253408	252000	244571
Landfill/Transfer station management	138100	6143	30150	8836	20000	7370
Fuel	90600	79398	84000	82935	70000	74022
Maintenance	26900	10951	35000	24441	30000	25301
Community mobilization	14350	1623	20725	2034	19000	4480
Other	61750	25445	58985	26888	71600	44246
Total	**621700**	**403023**	**482960**	**398542**	**462600**	**399990**

Source: OAG, 2015

Appendix 3: Percentage of expense on different activities of MSWM in KMC

Category of expenses	2011/12		2012/13		2013/14	
	Expenses	Percent	Expenses	Percent	Expenses	Percent
Salary and other facilities of sanitation personnel	279463	69.34	253408	63.58	244571	61.14
Landfill/Transfer station management	6143	1.52	8836	2.22	7370	1.84
Fuel	79398	19.70	82935	20.81	74022	18.51
Maintenance	10951	2.72	24441	6.13	25301	6.33
Community mobilization	1623	0.40	2034	0.51	4480	1.12
Other	25445	6.31	26888	6.75	44246	11.06
Total	**403023**	**100**	**398542**	**100**	**399990**	**100**

Source: OAG, 2015

Appendix 4: Opportunity and benefits from new proposed MSWM system in KMC

The existing solid waste management approach is based on obsolete system in KMC and operates inefficient. So, it neither creating any opportunity to use the waste nor protecting environment. The proposed framework is based on sustainable MSWM system which suggests involvement of public private partner (PPP) approach for the implementation. It is believed that the successful implementation of this framework will be able to address the following issues.

i. *Reduction in impacts on human health and environment and aesthetic value of the city*

Haphazard disposing and open burning of solid waste is common practice in KMC creating environmental pollution and impact on public health since current MSWM do not meet the proper environmental standards. This current landfill site was designed for disposing waste of Kathmandu valley for 3 years and started from 2005 as a part of temporary solution. Since then, waste generated is dumped still now in 2019. Residents live to the vicinity of this landfill are suffering from the smell from garbage and diseases spread from the open decomposition of the organic waste (Sutton, 2011;

Abualqumboz, 2016). In addition, the study reported that the decomposition of organic wastes in Sisdol landfills is generating greenhouse gases (Adhikari et al., 2015) and untreated leachate is polluting surrounding soil and water resources (OAG, 2015). Likewise, many rivers inside the cities are littered by full of trash and garbage which can damage the ecosystem of river as well as aesthetic value of water resources (US EPA, n.d., and NOWPAP MERRAC 2013)[16]. However, the proposed framework is structured to address all these issues.

ii. Minimize high dependency on import of fossil fuel

Nepal does not have particular reserve for natural gas, oil and coal. The fuel consumption in Nepal has been rocketing by 90% than before 5 years (CBS, 2018). This shows that huge amount of money is financed for importing fossil fuel. Therefore, different form of energy innovations and development such as energy from waste (WtE) is critically required to tackle this complete dependency on external source.

iii. Surplus of energy to fill electricity demand

The electricity demand has been continuously steep upward with the rapid increase of population and highly expanding urbanization in Nepal however, the supply has not been able to meet their demand. Although Nepal has abundant hydro resources with a potential of generating 83,000 MW of electricity in which about 43,000 MW of electricity can be utilized practically (ADB, 2014). However, the capacity of existing hydropower plants had just 802.4 MW or even less than 2% of the total potential of exploitable electricity generation by the end of 2016 (ADB, 2017). The public has to go through the regular scheduled load shedding and blackout all over the country during the dry season. Nepal is ranked 137th position in case of quality of electricity supply out of 147 countries (ADB, 2015) though it has enormous potential of power generation from hydro resources.

It is estimated that 27.6 million population as base year in 2014 will be increased by 1.37% per year and will reach to 39 million by the year 2030 (NPC and IBN, 2011). Resultantly, this has also projected the heavy urban growth and population will increase by 49% in 2030. This estimated trends show that per capita energy consumption will be increased tremendously over the time where total energy demand is projected to be 16.54 GWyr while 3.817 GWyr demand is for electricity for the year 2030. (NPC and IBN, 2011). Hence, the import of energy from external source cannot be the sustainable solution. In this scenario, the forecasted energy demand will be achieved if innovative and efficient technology will be implemented for generating different form of energy more specifically clean energy. Therefore, WtE

[16] http://www.waterencyclopedia.com/Oc-Po/Pollution-of-Streams-by-Garbage-and-Trash.html

can be the promising technology to generate renewable and sustainable energy to solve energy demand.

iv. Sustainable development goal achievement

Sustainable development goal (SDG) is the global goal with 2030 agenda as the blueprint to achieve the prosperous sustainable future for all (UN, 2015) and the 2030 agenda include 17 different goals. The SDG number 7 aims to access to affordable, reliable, sustainable and modern form of energy for all citizens. Clean energy as the essential part of the global strategies has been recognized for eliminating poverty, protecting the planet, earth and for ensuring the prosperous future for all[17]. The report published by National Planning Commission (NPC), Nepal on 2015 reported that currently about 75% of households are heavily dependent on solid fuel (traditional energy sources) as the primary source of energy and more than 25% of the households are using liquid petroleum gas (LPG) in Nepal. This picture evidently witnessed that the absence of access to modern and cleaner cooking facilities. Likewise, only 75% HHs has excess to electricity and remaining 25% of HHs lack electricity supply representing the supply and demand gap (NPC, 2015). Historically the nation's economic growth is strongly correlated to the nation's per capita energy use mainly electricity. The per capita electricity consumption in Nepal was 140 kWh which is the lowest energy consumption in South Asia (Shrestha, 2018). The electricity generation in Nepal is just reliant on hydropower with very negligible amount of solar and others and renewable energy shares only 12% of total energy consumption in 2015 (Shrestha, 2018).

In this scenario, the SGD goal for Nepal seem quite ambitious, in which the proposed target for 2030 include 99% of HHs with access to electricity, increasing the per capita electricity to 1500 kWh and reducing the commercial energy consumption per unit of GDP from 3.20 ToE/mRs to 3.14 ToE/mRs by 2030 (NPC, 2015).

Nevertheless, involvement of private sectors in energy development and the promotion of different form of renewable energy such as biogas generation from MSW by using appropriate WtE technologies can strengthen the energy situation on Nepal which ultimately help to meet the target (SDGs).

[17] http://www.searo.who.int/nepal/documents/