The Integration of Circular Economy into the Municipal Solid Waste Management of Kathmandu Metropolitan City in Nepal

Present Sector Challenges & Opportunities for Waste Material (Re)Utilization

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Abstract

The issue of solid waste generation and its effective management is one that is faced universally by society throughout the planet. With the inevitable increasing levels of urbanization and population growth, amplifying rates of solid waste and its appropriate management has become a significant challenge faced by communities, mainly in municipalities within developing countries. Inadequate management and disposal of municipal solid waste (MSW) leads to several types of pollution (i.e. air, water, soil) and is detrimental to both the environment and the health of all lifeforms present within it. In the municipality of Kathmandu in Nepal, which will be focused as the case region for this research project, effective management of solid waste is extremely difficult to achieve, due to a number of reasons including societal, economic, and technical restrictions, that will be discussed in the research project. The concept of circularity regarding waste management aims to improve existing incapable systems and practices employed by both private and public sectors in society, eliminating waste generation through the retention of the value of materials throughout their specific life cycles and post-utilization of recognized valuable discharged material.

The present research explores the possibility of integrating circular strategies concerning solid waste management (SWM) in the context of Kathmandu Metropolitan City from observing current practices in the municipality, identifying challenges and inadequacies faced by the system in place, and exploring an appropriate framework for the possible integration of Circular Economy (CE) within the waste management sector of the municipality. As the concept of CE is fundamentally built with the three pillars of sustainability in mind, which include the environmental, economic, and social aspects within society, this paper will analyze current practices and challenges regarding SWM in Kathmandu and base any recommendations for possible CE integration with impacts on the three aspects central to the research.

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1. Introduction

This chapter provides background information about the current situation of municipal solid waste (MSW) and its ongoing management in Nepal. The motivation and purpose of conducting this research will also be discussed.

1.1. Background

The management of solid waste is a major environmental issue in the majority of cities of developing countries around the world. Economic development and urban population growth are the primary causes for the critically increasing generation of MSW and is certainly the case with Kathmandu, the capital city of Nepal. Nepal is recognized to be one of the top ten fastest urbanizing countries in the world (United Nations, Department of Economic and Social Affairs, 2014), with the national census of 2011 recording the population of KV to be just over 1 million alone (CBS, 2012), and forecasted to double by 2030 which is an alarming statistic (United Nations, Department of Economic and Social Affairs, 2014). The management of the city's waste has experienced extreme difficulties for decades as a result, especially concerning the placement of landfills, where space for urban planning has become extremely scarce, and the widespread convention of illegal dumping of solid waste along river banks within the valley has also given rise to considerable public health and environmental problems.

The Solid Waste Management Act of 2011 (Government of Nepal, 2011) was drafted by the Government of Nepal aiming to maintain a clean and healthy environment through minimization of the damaging effects of solid waste on public health and the environment. Under this legislation, municipalities were given the responsibility for the construction, operation, and management of infrastructure for the collection, treatment, and disposal of MSW and also the promotion of reduce, reuse, and recycle (3R) strategies including waste segregation at source. The situation regarding effective waste management in the city, however, has not seen desired progression due to uncontrolled urbanization, lack of public awareness, the deficiency and inconsistency of reference information and data related to the functionality of SWM for the municipality, considerably intensifying environmental issues in the city as a result (Asian Development Bank, 2013b).

Due to the limited budget allocated for SWM from the Nepalese Government, developments and research in the waste sector of the country are heavily influenced by the involvement of the private sector through competitive bidding, by International Non-Government Organizations (INGOs) to be more precise. The management of solid waste has never been considered to be of leading priority, purely due to the fact that demand for other public services (i.e. healthcare, energy, food, etcetera) is much higher across municipalities in Nepal (Asian Development Bank, 2013b).

Another reason for the difficulty in implementing sustainable and effective SWM strategies in the country is the sheer complexity with regards to physical factors such as altitude, temperature, and humidity, in addition to sophisticated socio-economic factors such as economic status, consumption patterns and population, which are all dynamics that directly influence the types of waste generated as well as the remedial technologies to tackle its treatment and disposal (Asian Development Bank, 2013b).

1.2. Problem Statement

With the ongoing trend of an overwhelmingly increasing urban population, Kathmandu, like any other large city, possesses the responsibility of protecting its inhabitants through provision of a clean and safe environment, ensuring quality public health and economic opportunity for its citizens. Continual inadequate operation of municipal solid waste management (MSWM) due to a lack of sector funding and technical capacity, has noticeably hindered its ability to do so, thus creating a vicious cycle in which the generation of solid waste increases due to the absence of an efficiently functioning management system, and successful management of solid waste has become near impossible due to the alarmingly increasing amounts of solid waste. Possible implementation of circular economy (CE) principles to eliminate waste, through strategic utilization and consumption of materials and resources early on in the supply-utilization chain, throughout various sectors within the city, can present suitable strategic solutions for concerning SWM problems faced. As the concept of circular economy is a relatively novel and unexplored one in the context of Nepal and most certainly its municipal waste management sector, a suitable framework for its smooth integration with SWM will need to be investigated and assessed.

1.3. Research Objectives

The primary objective of this research is to formulate appropriate and feasible recommendations for the improvement of solid waste management (SWM) in Kathmandu Metropolitan City. An assessment of current procedures, their consequential environmental impacts, and observation of successfully implemented circular SWM practices in other developing countries will be investigated, for possible integration of CE principles into the waste management sector of the municipality. The core research question in this paper to investigate is the feasibility and possibility of developing a "circular" solid waste management system in Kathmandu Metropolitan City, where the term "waste" is to be redefined as "resources", and the municipality can proclaim compliance with the principles of "Zero waste to landfill[1]".

[1] 'Zero waste to landfill' refers to the practice of diverting as much waste as possible away from landfill through means of 3R (reduce, reuse, recycle) and energy recovery (Jones, 2017)

2. Literature Review

This chapter consists of an overview of key concepts and topics related to this research project and current knowledge of the matters supported by reputable sources and findings. The topics in this section include the impacts of inadequate MSWM, the role of Circular Economy in waste management, the current MSWM scenario in Kathmandu, and an evaluation of a national MSWM policy of Nepal.

2.1. Impacts of Inadequate Management of Municipal Solid Waste

Municipal waste is a direct consequence of everyday material utilizing processes in cities, ranging from a spectrum of sources including households, institutions, and businesses. With the unavoidable increase in population and trends of urbanization, managing this accumulation of waste becomes a real issue, from both an environmental and managerial perspective.

The effect that poor MSWM has on public health and safety is substantial. Solid waste that is not collected, treated, or appropriately disposed of can be a breeding ground for insects and pests, passing on air and water-borne diseases (Bhada-Tata & Hoornweg, 2012). The spread of diseases such as cholera, typhoid, respiratory allergies, etcetera, from unmanaged waste build-up and water pollution is a major concern in many developing cities around the world, with a staggering indication of 22 different human diseases linked exclusively to inadequate MSWM (P. Alam & Ahmade, 2013). Another study carried out by UN-Habitat also indicated that the occurrence of diarrhea is twice as high and severe respiratory infections six times higher in areas where waste is not collected regularly than in areas where collection is recurrent (Bhada-Tata & Hoornweg, 2012).

Incorrect MSW management and treatment also gives rise to environmental pollution, causing harm to the quality of air, water, and soil. For example, negligent dumping of waste fouls surface and ground water supplies. Casual open burning of MSW and unsuitable incineration have irreversible effects on the air quality as well and are major sources of black carbon (C40 Cities Climate Leadership Group, 2015). The mismanagement and accumulation of overwhelming amounts of solid waste contributes largely to climate change and global warming also. In many developing countries, MSW is habitually dumped in low-lying areas close to slums and along riverbanks and also openly burned, causing contamination of groundwater and surface water by leachate and air pollution respectively (Bhada-Tata & Hoornweg, 2012).

Another significant impact that poor MSWM has in society concerns the missed opportunity in the resource management of the types of waste accumulated. MSW can prove to be a valuable resource in a global market urgently moving towards recyclability and optimal utilization of materials.

According to UN-Habitat, the amount of post-consumer scrap metal is estimated to be about 400 million tonnes annually, with paper and cardboard making up 175 million tonnes per year alone, representing an estimated value of $30 billion per year on a global scale (Bhada-Tata & Hoornweg, 2012).

With the increasing costs of virgin material use and the environmental impacts associated with respective processes of their extraction and utilization, it is essential to preserve the value of secondary materials discarded as waste, through its reutilization if possible. Figure 1 shows the waste hierarchy, originally developed by Lansink (1979), highlighting the need for a reshuffle in the prioritization of the manner in how we as a society, perceive waste material and handle its disposal or possible reutilization. This is essential for the persistent security of the planet's resources in the fight towards sustainability for future generations.

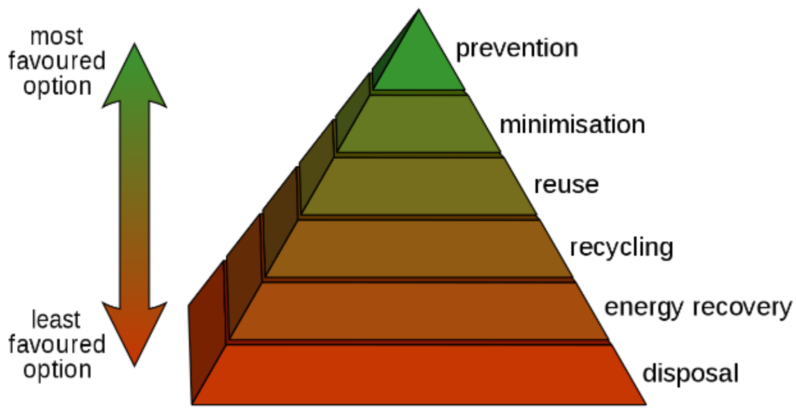

Fig.1 The Waste Hierarchy *(C40 Cities Climate Leadership Group, 2015)*

2.2. The Role of Circular Economy in Solid Waste Management

With the incessant depletion of natural resources reflected by our consumption-fixated lifestyles as a society, it has been increasingly difficult to carry on like this if a sustainable future is to be secured. One approach to tackle this global issue is to redefine how we view and manage the waste we produce. A shift from conventional linear Integrated Waste Management Systems (IWMSs), which concern explicitly on the treatment of MSW regardless of how much is produced, to circular IWMSs (CIWMSs) has become a necessity. CIWMSs function with the core principles of CE embedded into them connecting both waste and material management, emphasizing on the full utilization and preservation of the value of all materials, including MSW (Cobo, Dominguez-Ramos, & Irabien, 2017). CE integration into waste management aims to remove the entire concept of waste, returning components to form part of natural (biological) or industrial (technical) cycles, with minimal consumption of energy doing so. Organic waste will therefore be biodegraded, whilst non-organic industrial waste will be intended to be reused in a basic way with low energy costs (Cuadros Blázquez, González González, Sánchez Sánchez, Díaz Rodríguez, & Cuadros Salcedo, 2018).

As the consumption of raw materials rises, an increase in waste generation is also experienced. Approximately 1.3 billion tonnes of MSW are produced in cities around the world on an annual basis (Bhada-Tata & Hoornweg, 2012), with developing countries contributing to the majority of the global waste through the continual waste disposal in open dumpsites, lacking appropriate frameworks to cope with the unmanageable amounts of waste and environmental hazards that arise from its build-up. In the case of overpopulated cities around the world, there is a tendency from governments supporting the formulation of policies against landfilling, due to the limited space available and possible interference with other land utilizing sectors such as agriculture (Moh & Abd Manaf, 2014).

Waste valorization[2] is a novel concept at the very heart of waste circularity[3], involving the reutilization of valuable materials extracted from wasted matter to regulate the consumption of raw materials and eliminate unnecessary energy intensive procedures involving the processing of virgin materials (Waste Wise Products Inc, 2017). An example of this in practice is food waste valorization for the production of chemicals, materials, and fuels in South Asian countries including India, Singapore, Thailand, Malaysia, and Indonesia. In India, for example, conventional energy conversion technologies are employed to manage the substantial amounts of MSW generated. These include landfill waste-to-energy (WtE), refuse-derived fuel (RDF) and biogas (Ong, Kaur, Pensupa, Uisan, & Lin, 2018). Bioethanol production has been adopted in India on a large scale, with the valorization of waste into value-added products the next future priority. Food waste streams have been identified as being rich in proteins, biopolymers, and carbohydrates which if recovered, can be productively applied in pharmaceutical, food, and chemical industries (Arancon, Lin, Chan, Kwan, & Luque, 2013). Innovative valorization technologies will play a vital role in the effective management of MSW and WtE techniques such as bioenergy generation, are enormous opportunities that should not be overlooked. Nepal, like India, is a country driven mainly by agriculture and could benefit greatly through the transitioning of its current conventional linear waste management model into a more circular and sustainable one.

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[2] The concept of waste valorization refers to any industrial processing activity intended to reuse, recycle, or compost from waste material (Kabongo, 2013).

[3] Waste circularity refers to the adoption of circular economy principles into the waste supply chain, thereby redefining products by completely designing out waste, whilst minimizing negative impacts to the environment (Ellen MacArthur Foundation, 2013).

2.3. Sustainable Solid Waste Management

A sustainable solid waste management system is defined as one which prioritizes actions according to the waste hierarchy (see figure 1), by emphasizing the importance of waste prevention rather than its reduction, treatment and disposal. It also focuses on the extraction of optimal practical usage from products and by doing so, generating the least amount of waste possible (C40 Cities Climate Leadership Group, 2015). Setting the correct priority order for SWM generates numerous environmental, economic, health, and social benefits in society (C40 Cities Climate Leadership Group, 2015). It also enhances aspects such as public health, air quality, poverty reduction, and overall development, which amplify the importance of proper waste management as these benefits are of utmost priority to societies universally.

The concept of Integrated Sustainable Waste Management (ISWM) is a continually improving one as it is solely developed and built out of experience. It aims to address problems with MSW in low and middle-income and also transitioning countries (Klunder & Anschütz, 2001). The term 'waste' is rather subjective, in a sense that it can carry a different meaning from one individual to another. A product or material unwanted by the first user could possibly be of significant value for another in a different circumstance. For instance, reutilization of household paper, plastic, and metal 'waste' by relevant industries from are prime examples that highlight this fact. ISWM not only views waste solely as disposables, but also as opportunities providing potential sources of income, which differentiates it from the conventional perception of waste management. In the majority of low-income and developing countries, waste can be the only free resource available to the poor who are unable to access common property resources available in their country, which is evident from the significant growth informal sectors existing from mass waste collection and recovery (Klunder & Anschütz, 2001).

When concerning the overcoming of issues relating to waste management, there is an inclination to prematurely jump to solutions of the problems faced, without any thorough analysis of the current situation in place, which is where the insight of ISWM can play a pivotal role. It emphasizes that the majority of waste management problems originate from the attitude, behavior, and perception of society towards waste, managerial (in)capacities, the institutional framework, the environment itself, and the socio-cultural context, rather than the lack of available capital and adoption of state-of-the-art technologies, which are often the obvious restrictions in the development of a functioning waste management system identified (Klunder & Anschütz, 2001). ISWM aims to avoid the incorrect and irresponsible use of money and equipment for the many problems they are unable to solve, by the promotion of technically applicable, economically feasible, and socially acceptable solutions that best suits the concerned environment, economy, and society to resolve, without degrading the environment, waste management problems in cities in the global south.

The ISWM framework is based on its four key principles which are as follows (Klunder & Anschütz, 2001):

1. **Equity:** Citizens' entitlement to a proper waste management system to benefit the environment and their health.
2. **Effectiveness:** The waste management model implemented should lead to the safe removal of all waste.
3. **Efficiency:** Waste management system operated by maximizing benefits, minimizing the costs, and optimizing the use of resources.
4. **Sustainability:** Waste management system is suited to local conditions and is feasible from a technical, environmental, financial, institutional, political, and social perspective, whilst being able to sustain itself over time without exhausting the resources upon which it depends on.

Based on the concept of ISWM, there are three central dimensions in waste management; the stakeholders involved, the fundamentals of the waste system, and the aspects of sustainability (Klunder & Anschütz, 2001). Stakeholders have specific roles, responsibilities, and interests when concerning waste management. In many developing countries such as Nepal, there exists stakeholders external to the official municipal workforce engaged in activities related to waste management such as reuse and recycling. These could include informal sector waste pickers who gather waste material from the streets or dump sites, wandering waste collectors who buy unwanted items door to door from households, and independent recycling enterprises. Secondly, the fundamentals of the waste system are essentially stages across a movement or flow of materials from its extraction to its final treatment and disposal. ISWM defines and divides the fundamentals of a waste system into the conventional stages of 'collection', 'transfer', and 'treatment' or 'disposal', whilst giving equal importance to the less well valued elements of 3R. The third dimension of waste management, the ISWM aspects, allow for existing waste systems to be analyzed and improved upon, providing the tools to study and create solutions to tackle various issues faced by the sector. For example, environmental aspects emphasize on the effects of waste management practice on land, water, and air, economic aspects involve the capacity to budget and account for costs within the waste management system, and socio-cultural aspects examine the effects of culture and society on waste generation and its management.

The following figures show firstly a complete theoretical ISWM model, aiming towards a more sustainable future with regards to waste management, and a real-world application of a ISWM system in the city of Porto, Portugal, in which a circular and systematic waste stream system can be seen.

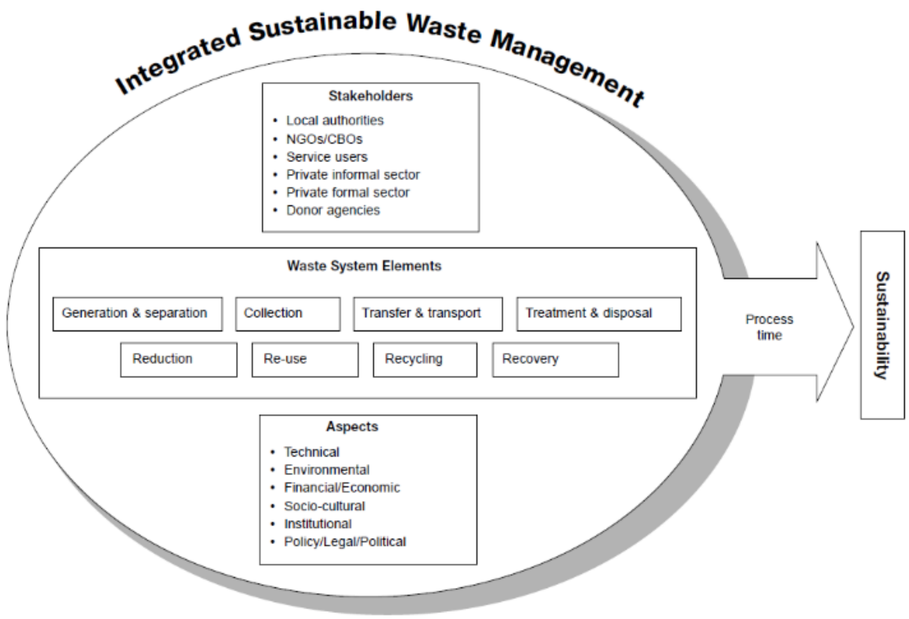

Fig.2 The ISWM Model *(Klunder & Anschütz, 2001)*

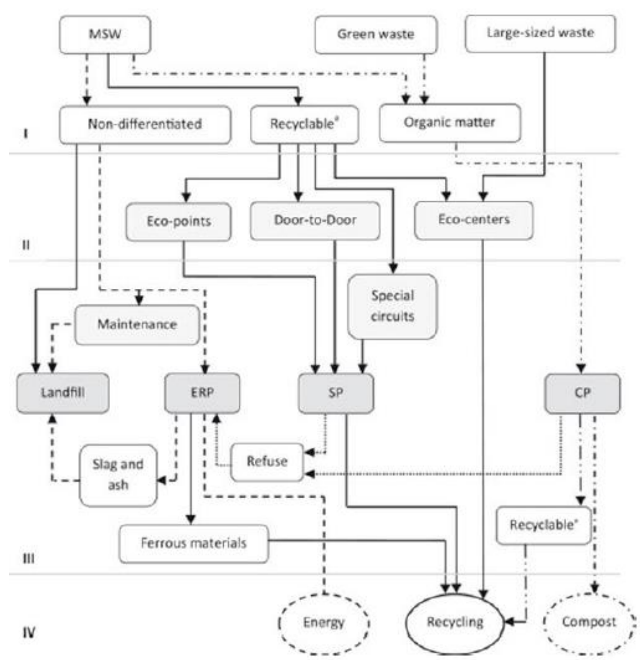

Fig.3 A real-world implementation of ISWM in Porto, Portugal
ERP (Energy Recovery Plant), SP (Sorting Plant) and CP (Composting Plant).
I – Residential production and disposal; II – Councils production and disposal; III – Valorization and treatment; IV – Waste material conversion (Herva et al., 2014)

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2.4. Waste Valorization

A gradually evident shortage of the Earth's resources through irresponsible and strenuous exploitation by mankind has led to the exponentially increasing amounts of waste worldwide. MSW is characterized as waste generated by households, as well as commercial and any waste with similar composition to household wastes (Maina, Kachrimanidou, & Koutinas, 2017). The amount of MSW accumulated on a global scale per year is recorded to be approximately 1.3 billion tonnes, with an alarming projection of it to rise up to 2.2 billion tonnes by the year 2025 (World Bank, 2018a).

In order to tackle this worrying issue, the importance of not only resource management, but also potential recovery and reuse of waste materials has been experienced globally. As previously mentioned, the concept of 'zero waste' has given new meaning to the term 'waste' and its conventional denotation, implying it as something that is unwanted or meant to be disposed of. Zero waste is defined as a goal that is ethical, economical, efficient and visionary, with a purpose to guide society towards changing their lifestyles and behavior to model sustainable natural cycles, where all discarded materials are intended to become resources for others to use (Zero Waste International Alliance, 2004). Waste valorization can be seen as an aspect of circular economy in practice within the waste management sector. It closes the material loop by utilizing elements extracted from waste where possible. Waste can potentially contain valuable materials such as metals and minerals, highlighting a potential profitable opportunity that could benefit both a country's economic development and also promote a cleaner 'zero waste' culture and environment in the process.

Waste valorization is an important step in the shift towards a circular economy as rapid growth of global population has both resulted in an increase in waste per capita whilst also triggering increasing demands for food, energy, and industrial end-products (Maina et al., 2017). Waste valorization aims to abolish and replace the dominant and conventional economic development model of "take, make, and dispose" with concepts of circular economy and bio-economy, where efficient resource (re)utilization compensates for the environmental, economic, and societal difficulties caused by the linear model of resource exploitation, thus encouraging environmental sustainability.

For example, even though attempts have been made to reduce the amount of material and products being wasted, the agricultural and food industries carry on contributing to inescapable large organic waste streams worldwide. This particular waste comprises mainly of leftover crop residues or rejected food products which are normally landfilled. This highlights an opportunity for biomass valorization ranging in forms of something as simple as composting and using the waste stream as animal feed, to complex processes involving chemical and material extraction from the waste stream.

Biomass waste valorization can be divided into three primary categories depending on the end-use of the waste material (Six, Velghe, Verstichel, & De Meester, 2016). Firstly, 'direct use' of organic waste corresponds to valorization in its simplest form, an example in which crude waste material is utilized for feed applications. The second option is 'material recovery', which involves chemical extraction and/or conversion of biomass into useful products such as fertilizers and solvents. Finally, 'energy recovery' is one more intriguing valorization process in which biomass or biogas generated from anaerobic digestion (AD) of organic waste, is burned and utilized as an energy resource.

Although the focus for recognizing and utilizing sustainable and renewable sources of non-fossil fuel energy is primarily on popular technologies such as wind and solar energy systems, municipal waste contains a large portion of material that is biological in origin, holding promising potential for renewable energy. Material such as wood, paper, food residue, and garden waste are all grouped as biogenic waste and so, can be considered to be renewable resources (Breeze, 2018a). The renewable content within waste is variable depending on the mixture and so, it is essential to establish just how much of the waste material is biogenic in order to confirm what proportion is exploitable as a source for renewable energy. To ensure dependability and efficiency of the material extraction and utilization processes, sorting and separation of biogenic material with complete removal of any non-biogenic material such as plastic, glass, and metal, is fundamental.

Ever since the Paris climate change agreement of 2015 (UNFCCC, 2015), there has been a growing interest and a sense of urgency in the adoption of any potential renewable resource initiatives to help achieve emissions targets set by countries all over the world. An advantage of utilizing the renewable portion of waste is that it has the capability to provide an incessant supply of energy unlike other RETs such as solar or wind energy. The current linear fossil-based economy has given rise to critical issues to the environment, such as rapid economic expansion, irreversible climate change concerns, and unmanageable unprocessed waste disposal into natural habitats. With the continually increasing amounts of solid waste generated worldwide, focus has been put on waste valorization process to redefine organic waste as a renewable resource feedstock used to recover bio-based materials and energy, with an aim to end the widely practiced act of landfilling, safeguarding the environment and enabling society to transition towards a more sustainable circular bio-economy (Mohan, Butti, Amulya, Dahiya, & Modestra, 2016).

2.5. Waste-to-Energy (WtE) Technology

Municipal waste, and more specifically, urban waste, is normally generated in large volumes and its collection and disposal can be rather costly and time consuming. A fraction of this waste consisting of paper, glass, and metal cans can all be recycled effectively through separation at source or at sorting facilities. Organic waste can be separated and left to decompose naturally as soil-enriching compost too. Nevertheless, there always remains a substantial residue within MSW that leaves massive economic potential for possible beneficial utilization. Making use of the otherwise discarded residual waste has become a quite attractive solution to address issues related to both waste management and sustainable energy.

Historically and even in some countries today, open combustion of residual waste has been widely exercised, solely to reduce the build-up of waste for disposal, often carried out without any intention to generate electricity or heat. Residual ash accumulated as a result of this is then buried in a landfill site. This practice is damaging to the environment and poses numerous health issues for society due to both the harmful emissions from open unregulated combustion itself, and soil contamination from the potentially toxic untreated residual ash waste from landfilling. Advancements in combustion technologies however, has allowed for the generation of electricity and heat from the energy released from the waste, thus offering a much more environmentally friendly remedy to the issue (Breeze, 2018a). Even so, numerous considerations have to be taken into account such as atmospheric emissions, global warming, and climate change, with strict regulations administered regarding combustion processes of municipal waste in many parts of the world.

Biological waste, comprising of wood, paper, and agricultural products can be deemed to be renewable resources, and their combustion, while emitting carbon dioxide, has a relatively minimal impact on the overall atmospheric load. This is due to such waste materials being part of shorter biological cycles, in which similar materials are once again formed, reabsorbing the carbon dioxide from the atmosphere to counteract the initial combustion process in principle (Breeze, 2018a). The combustion of plastics, however, have a much more significant and damaging impact on the atmosphere with greater quantities of carbon dioxide released, as they are generally made from fossil-fuel based materials.

The most widely applied and straightforward method of generating energy from waste involves the burning of combustible biological waste material inside a contained boiler, thus generating heat which is then utilized to produce steam, in turn driving a steam turbine generator to ultimately produce energy. These processes are categorized as *'thermal conversion'* or *'mass burn'* technologies (Breeze, 2018b) and the energy generated from such processes depends on the quality of the input waste material (i.e. its energy content or calorific value), and even still, these processes generally have a maximum efficiency ranging from 25-30% (Breeze, 2018a).

Mass burn technologies are commonly used in most European countries and involve specially designed mobile grates placed on an incline, causing the waste material to move across the grate under the force of gravity. The waste spends a lengthy period inside the furnace ensuring complete combustion.

The operation of a WtE mass burn plant typically involves waste being transported firstly to a sorting facility, where it is stored in a strictly contained environment to avoid external pollution. Recyclable materials such as plastics and metals are removed prior to the transfer of the useable waste to the furnace. Combustion of the biological waste is initiated at temperatures typically above 1000°C but below 1300°C to ensure the elimination of chemicals whilst unaltering the content and composition of the ash that is formed (Breeze, 2018b). The heat generated from combustion is then captured within a boiler to produce steam, which drives the turbine to generate energy. The residual material left as a result of the combustion process is removed with any remaining solid particles being recycled back into the furnace. Exhaust gases from the combustion and boiler systems are cautiously treated, with metallic and organic residues absorbed and extracted if possible. A particle filter then screens out any solid particles passed along with the flue gases to fully ensure that emissions leaving the plant are sufficiently clean to be released into the atmosphere. Dust and residue from the gas filters are usually carefully landfilled, whereas the more substantial combustor residue has potential to be reused for road construction (Breeze, 2018b). Figure 4 below illustrates the operation of a WtE mass burn plant.

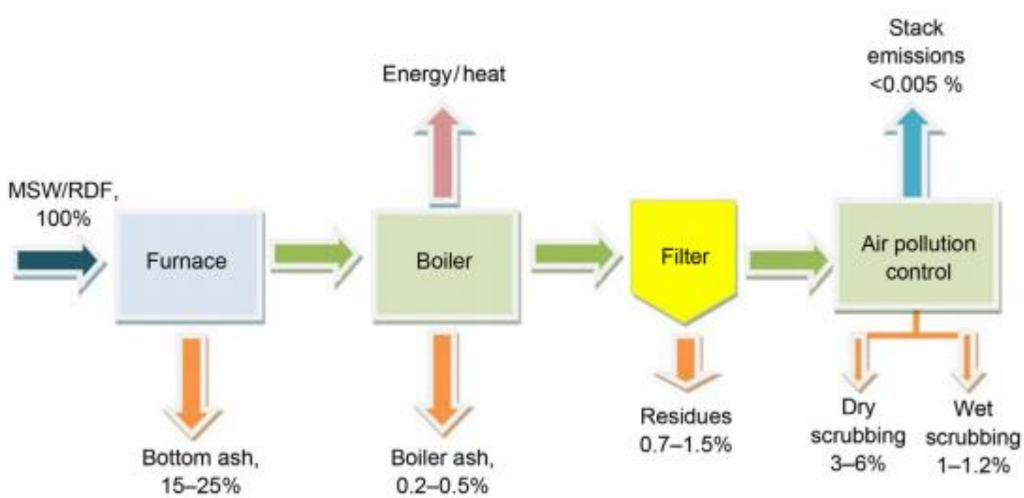


Fig.4 Waste to energy mass burn plant process schematic diagram *(Waste C Control, 2018)*

Another method which is popular with extracting energy from biological waste is through '*anaerobic digestion*'. This process involves the natural decomposition of organic material under the influence of microorganisms in the absence of oxygen (Breeze, 2018b). Anaerobic digestion (AD) happens naturally in soil and lakes but the same process can be replicated with unique digesters to handle organic waste material.

The primary by-product of AD on is a combination of gases, with methane being the prime constituent, which allows for energy generation. This 'biogas' is also produced as a result of AD triggered by soil bacteria within municipal waste accumulation in landfills and collection and utilization of the gas for energy generating purposes has been adopted in many countries worldwide(Moya et al., 2017).

Biogas technologies are categorized into 'wet' and 'dry' procedures in which wet AD techniques involve fewer solid waste components and dry AD techniques contain more solid waste elements (Moya et al., 2017). In both cases, biogas is utilized either to generate electricity or to produce heat with wet digestion technologies predominantly applied in the treatment of municipal wastewater and dry digestion employed to manage and make use of MSW as a valuable resource. The production of biogas greatly reduces the amount of waste accumulated and thus, moderates the need for landfill disposal.

Innovative WtE technologies have emerged in recent years shaping the perception of waste from material that we discard to a valuable resource we can exploit. '*Pyrolysis*' is one such thermal conversion technology which involves the thermal degradation of solid waste in the absence of oxygen. It is a partial combustion process which requires retaining temperatures between 300 to 800°C and separation of metals, glass, and inert materials such as sand or concrete (Moya et al., 2017). Thermal decomposition of the organic waste material is generally initiated at 300°C in an oxygen-free and non-reactive environment, with an increase in temperature to 800°C causing in the formation of the by-products of the pyrolysis process, comprising of a mixture of predominantly solid 'char', accompanied with gaseous and liquid residuals (Agarwal, Tardio, & Venkata Mohan, 2013).The gaseous by-product of pyrolysis is known as 'syngas', a composition of methane, hydrogen, carbon monoxide and carbon dioxide, and can be burned to generate energy or condensed to produce bio-fuels (Moya et al., 2017). Pyrolysis processes can also handle biomass and plastic materials with the emergence of state-of-the-art 'plasma pyrolysis' technology being employed to produce syngas by transforming plastic waste with high *calorific value*[4]. The pyrolysis process is presented in figure 5.

[4] The *calorific value* is the amount of heat produced by the complete combustion of a given mass of a fuel and is usually expressed in joules per kilogram (J/kg). It is the conversion factor of a fuel quantity from natural units (such as mass) into energy units, which expresses the heat obtained from combustion of one unit of the fuel. (Energy Statistics Manual, IEA, 2004)

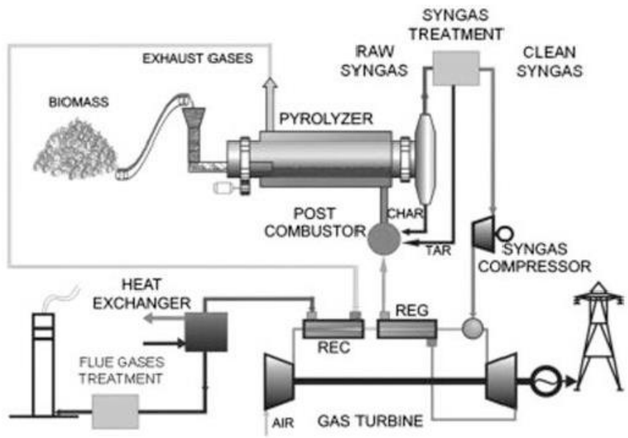


Fig.5 The Pyrolysis process *(Moya et al., 2017)*

'*Gasification*' is another thermal conversion WtE process, involving partial oxidation with the main by-product being syngas, which can be expended like natural gas (Moya et al., 2017). This energy-rich and clean syngas produced through gasification essentially closes the loop on waste's lifecycle, with the energy embedded in the waste having the capability to be utilized to power machinery that generate electricity. Like pyrolysis, it occurs at high temperatures to create a combustible, low calorific value gas that can either be burned in a gas engine or a traditional boiler system (Breeze, 2018b). Gasification has the potential to reduce waste mass by 70% and over 90% of the volume of waste, whilst curbing greenhouse gas emissions and providing a viable alternative to landfill disposal (Arena, 2012).

The main distinction between gasification and pyrolysis involves the difference in proportion of the specific end product. In the gasification process, biomass or waste is heated in a vessel to produce syngas exclusively, whereas the product of pyrolysis is predominantly solid char with syngas more of a residual component (Renewable Energy Association, 2013). A low oxygen environment allows for molecular material breakdown and the gasification process reconstructs the molecules to form the syngas, which can be used as a fuel to generate energy. The syngas is totally cleaned of any impurities or toxins prior to its use in the case of gasification, unlike conventional WtE methods such as incineration, where emission treatment is carried out post-combustion, creating complexity in trying to contain and isolate environmentally damaging emissions (Aries Clean Energy, 2017).

One of the main advantages of gasification is that the process does not emit any GHGs, contrary to landfilling practices, where large volumes of harmful methane gas, if not carefully captured, is released from the soil into the atmosphere, where it can be up to 25 times more fatal as a heat-trapping gas compared to carbon dioxide (Sodari & Nakarmi, 2018). Transportation of waste material to landfill sites are usually operated by fossil-fuel-powered trucks, which contribute to a large portion of GHG emissions. If gasification plants are set up in a way that readily available waste can be regularly fed into the system, a considerable amount of harmful emissions can also be further avoided from trucking.

Unlike incineration, gasification occurs in low oxygen conditions and does not involve the burning of input waste, which averts the formation of ash, dioxins, and gases like sulfur oxide (SO_X) and nitrogen oxide (NO_X), which are injurious to both human health and the environment. Much of the input waste in a typical WtE gasification plant is transformed into syngas, with a secondary by-product being valuable high-carbon biochar, which shares many chemical properties with charcoal. This can in turn be reused as fuel for cement kilns, soil enhancers to help retain water and nutrients, and also as filtering agents for liquids or gases (Aries Clean Energy, 2017). Figure 6 shows a simplified breakdown of the gasification process.

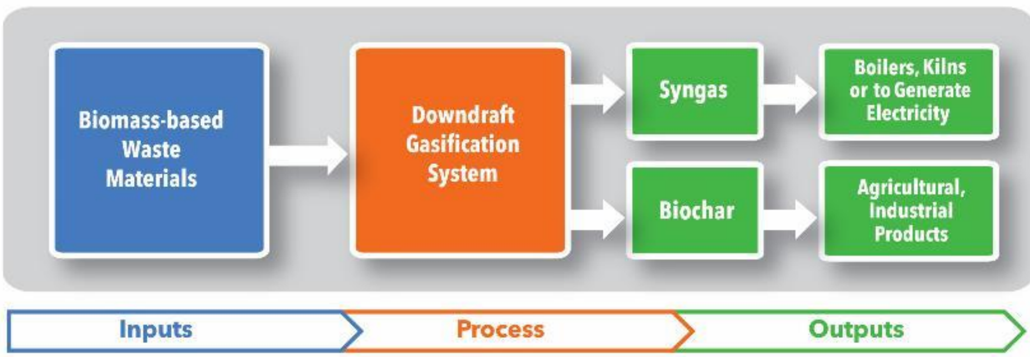


Fig.6 The Gasification Process *(Aries Clean Energy, 2017)*

The technologies discussed previously principally entail converting waste material to energy within dedicated WtE plants. However, another alternative exists in which waste is first sorted and then converted into usable fuels for use in industry and conventional power plants. These fuels are known as refuse-derived fuels (RDFs) and are produced by firstly segregating and removing all non-combustible material such as metal, glass, and stone from the waste to be processed (Breeze, 2018b). The combustible segment is then formed into pellets and sold and utilized as an alternative fuel which can be mixed and burned with biomass waste in power plants. As the process of producing RDFs requires sorting with extreme precision, this method is most suitable in circumstances where recycling is widely practiced and well established. Figure 7 shows an assortment of such refuse-derived fuel pellets.

Fig.7 Refuse-derived fuel pellets *(Power Max, 2018)*

Table 1 below presents the advantages and disadvantages of each of the discussed WtE technologies, taking into consideration their environmental, economic, and technological impacts. It is essential to develop an understanding of both the benefits and drawbacks of all of the available WtE technologies, to appropriately and exclusively enhance SWM, given the context of variable circumstances.

Table 1. Advantages & Disadvantages of WtE Technologies.
Formulated using *(Moya et al., 2017), (Breeze, 2018b)*

WtE Technology	Advantages	Disadvantages
Anaerobic Digestion (AD)	• High availability of feedstock (i.e. organic waste material) • Used in landfills • Low level of sludge generation • Low operational temperatures • Lower emissions than thermal WtE Technologies	• Longer operating times to obtain methane and organic matter degradation • High initial costs/capital investment required • Can produce foul odors if influent is high in sulfur or methanogens[5] • Waste separation is required
Pyrolysis	• Flexibility of equipment for installation • Waste separation is not necessary • Immediate degradation of toxic components and pathogens	• Requirement of high temperatures • Complex process • High operational and investment costs • Installation of air purification is necessary to treat flue gases • Production of ashes containing high heavy metal content
Gasification	• Low oxygen environment limiting the formation of dioxins, SOx and NOx • Requires a low volume of process gas, and thus, smaller and less expensive gas cleaning equipment • Better volume reduction than incineration or pyrolysis	• Output gas contains various hazardous particulates, heavy metals, and tars • Limited feedstock variability • Higher capital expenditure required than conventional WtE technologies
Incineration	• Established and widely deployed technology • Elimination of groundwater contamination	• Emission of toxic pollutants including carbon dioxide, sulfur dioxide, nitrogen oxide, carbon monoxide, and volatile heavy metals • High operating and opportunity costs
Biorefineries (waste-to-bioproducts)	• Can utilize a variety of biomass resources, whether derived from plants or animals • Potential to utilize optimum energy of organic wastes • Biomass wastes can be converted into either gaseous or liquid fuels	• Variation in renewable-based feedstock • Diversity of complex technologies to obtain end products

[5] Methanogens are microorganisms that produce methane and obtain metabolic energy from the biosynthesis of methane (ScienceDirect, 2011).

2.6. The Energy Situation in Nepal

As a suitable WtE technology will be proposed as a part of the recommendation for a sustainable MSWM system in KMC, this section aims to provide background information concerning the energy situation within the country. The renewable energy potential, the issues faced regarding energy security, limitations of the energy sector, and its consequential effect on the nation's sustainable development are topics that will be investigated.

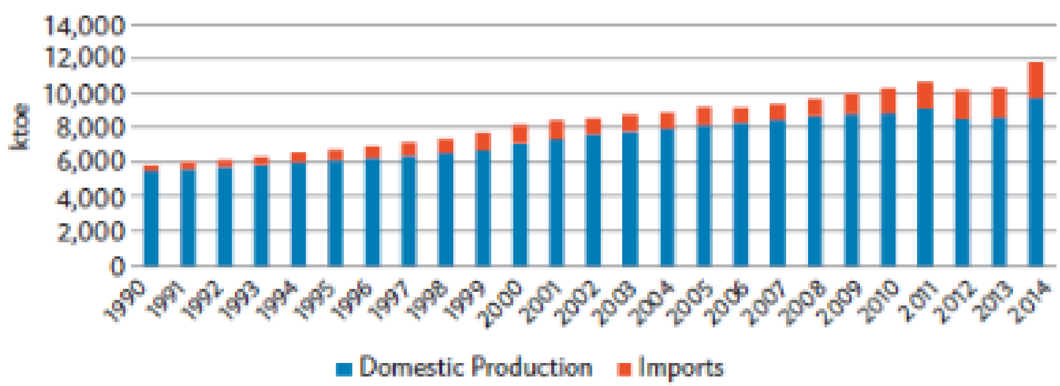
Energy is a necessity in modern society and is at the forefront when it comes to the socio-economic development of a country. More than 80% of Nepal's population reside in rural communities where reliable energy provision is insufficient or even unavailable. Nepal is one of the least developed countries in the world with the energy sector being fundamentally dominated by the use of conventional energy sources such as fuelwood, animal dung, and agricultural residues for domestic use. Presently, around 40% of the population have access to electricity out of which only 29% accounts for rural electrification (Surendra, Khanal, Shrestha, & Lamsal, 2011) . In addition, the fossil fuels consumed in the country are all imported in refined form from neighboring countries like India and China as Nepal does not possess fuel or coal reserves of its own. Despite the nation possessing great potential in harnessing various renewable energy resources such as hydropower, solar power, wind power, and bioenergy, the implementation of energy technologies have not been sustainably applied due to several reasons involving geography, politics, finance, and limitations in technology. Approximately 25% of the population has access to electricity through renewable energy sources, of which, 30MW is generated from mini and micro hydro schemes, 15MWp from solar PV systems, and 20kW generated from wind energy technology (Ministry of Population and Environment, 2016).

Being a country with an immense potential for renewable energy generation and a diverse topography possessing a theoretical hydroelectric potential of nearly 90,000MW of electricity generation(F. Alam et al., 2017), water is distinctly the most significant energy resource in the country. Nepal, however, has not been able to harness even 2% of its viable power generation potential to date (F. Alam et al., 2017). This is due to several reasons which include geographical, technological, political, and economic setbacks.

Alternate renewable energy sources abundantly available in the country are solar, wind, and biomass with the renewable sector still in its development phase. Due to an insufficient energy supply with an absence of any coal or gas reserves of its own, Nepal's economic and social development faces constant obstruction. As the energy sector is viewed as the country's key contributing sector with regards to future economic growth and development, renewable energy development has gradually begun to surface.

The Brundtland report (Brundtland, 1987) revolutionized the way we perceive and prioritize sustainable development today, stating that "*sustainable development should meet the needs of present generations without compromising the ability of future generations to meet their needs*." Sustainable Development and growth of a country is interlinked and directly influenced by the energy generation and consumption practices and behaviors, and this relation is certainly evident with the case of Nepal's current energy situation.

In Nepal's case, the primary energy supply mix is dominated by biomass, in the form of firewood, agricultural waste, and animal dung, the reason behind this being the lack of reliable alternative energy sources along with the poor state of the country's economy, particularly noticeable in the rural areas. As Nepal does not have any known deposits of oil, coal or gas of its own, it has forced the import of such conventional fuels from neighboring countries like India and China, which has grown by a significant amount over the years compared to the restrained production growth of indigenous primary energy in the country. The energy imports have grown from 312 ktoe in 1990 (5.4% of the primary energy supply in that year) to 2,069 ktoe in 2014 (17.7% of the primary energy supply) (Asian Development Bank, 2017), which is a staggering statistic, emphasizing the nation's dependence on external sources for its energy needs and urgency due to lack of development of sustainable energy solutions. This is a clear indication that energy security and progression is a direct reflection of a nation's overall sustainable development and vice versa. Figure 8 below shows Nepal's domestic energy production and import trend from the years 1990-2014 depicting the growth imbalance in native energy generation and energy imports.

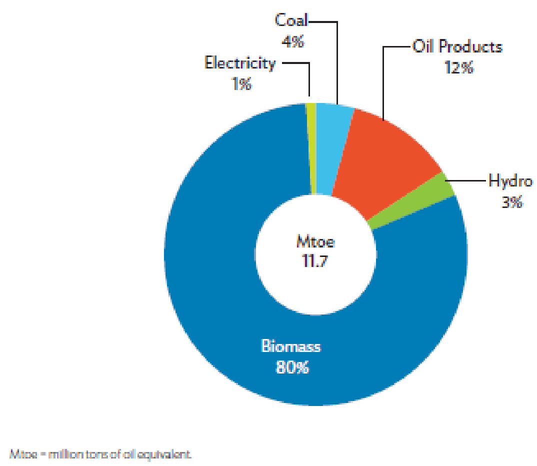


Item	1990	1995	2000	2005	2010	2014
Domestic production	5,501	6,138	7,138	8,152	8,876	9,740
Imports	312	616	1,037	1,052	1,418	2,069
Total	5,813	6,754	8,175	9,204	10,294	11,809

ktoe = kilotons of oil equivalent

Fig.8 The annual comparison of domestic energy production and the import trend of Nepal from 1990-2014 *(Asian Development Bank, 2017)*

In relation to its gross domestic product (GDP), Nepal has a significantly high energy consumption when compared to the likes of other South Asian countries like India and Bangladesh. The total energy consumption in 2015 was 460 million GJ with 50% of the total consumption contributed by the burning of firewood for energy, which poses as a real threat to the country's forests (Ministry of Finance, 2016). 82% of the population use solid fuels such as wood, charcoal, dung, etc. as cooking energy with this percentage rising to 90% in rural areas (ESCAP, 2014). Renewables, predominantly hydropower, contribute to about 3% of the total consumption which is extremely surprising, considering the great potential possessed by the country. Figure 9 below portrays the primary energy supply mix and the consumption sectors, with the use of firewood in rural region households causing the large share coming from biomass use.



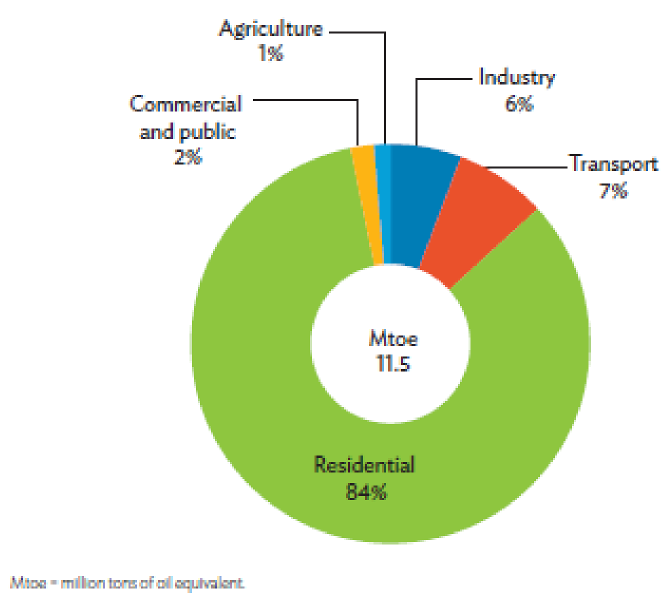


Fig.9 Nepal's primary energy supply mix and final energy consumption mix for 2014 respectively

(Asian Development Bank, 2017)

Concerning sustainable development of the nation, the fundamental goal has always been to accelerate overall poverty reduction and provide both its current citizens and successive generations not only with the bare necessities for their livelihood, but also the most comprehensive prospects in the economic, social, political, cultural, and ecological aspects of their lives. The sustainable development agenda intends to focus on both the country's current and potential strengths, along with its many vulnerabilities. Nepal's strengths on the road for a sustainable future consist of its large hydropower potential, unique biodiversity, appealing marketable landscape, fertile agricultural lands, favorable climate, and diversity with regards to its people and cultural heritage. Nepal, being a landlocked country and its economy heavily influenced by the economies of two large neighboring countries in India and China, make it very difficult to flourish economically let alone compete in the world market. Political instability due to only recently becoming a democratic nation in 2008 has also resulted in the need to arbitrate political interests concerning economic, societal, and energy development plans which is another barrier for sustainable development. Another issue of climate change and the effect it may have on the monsoon season affecting the agricultural system, the melting of the Himalayan glaciers, and the threat it possesses for the survival of the country's biodiversity, is one of critical concern. All the mentioned strengths and vulnerabilities, with appropriate management and assessment, could allow for innovative breakthroughs and progression with respect to the dimensions of sustainability and development.

As mentioned previously, the high dependency on the import of fossil fuels has led to the poor management of Nepal's own national energy generation and supply system. The energy challenge faced on the *national market scale* that will be discussed is the *incapacity of the supply-side of energy provision to the public*. This shortage of energy capacity is a key challenge faced by the country, and can be divided into four core issues that have resulted in the shortcomings of the energy sector in the country:

High Dependence on Import for Fossil Fuel Supply

Being a landlocked country and having no evident in-house fossil fuel reserves, most of the fossil fuel demand of the population in Nepal is covered by imports from India and has been the case for the past 40 odd years. A long-term agreement contract with the Indian Oil Corporation (IOC) has been in place for the regular supply of petroleum products including gasoline, diesel, and kerosene, and although it has most certainly facilitated a significant portion of the energy needs of the Nepalese people, this dependency has somewhat stunted the development of home-grown solutions with regards to addressing the country's own energy needs, resulting in a poorly managed energy supply network highly reliant on external support.

Furthermore, the weakness of the country's energy capacity was highlighted in September 2015, when political tension along the Nepal-India border caused a blockade, completely cutting off the incoming supplies of fuel from India, rendering Nepal to a virtual standstill for two whole months over its typically harsh winter period (South Asians for Human Rights, 2016). Although the situation regarding the border relations has somewhat improved since then, the delivery of cooking gas and diesel have not reverted to their normal state. An energy crisis of such scale and duration has severely hindered economic and social development within the country and there is continuous fear of another state of emergency such as this occurring in the unforeseeable future.

Electricity Crisis

With the evident global depletion of fossil fuels, Nepal finds itself in a very threatening position with regards to guaranteeing its own energy security. Its inability to fully exploit its hydro power generation potential with inadequate project planning, delays in implementation, and underinvestment in the sector, has made it extremely difficult to match the progressively increasing national energy demand. The deficiency in national energy supply has resulted in forced regular scheduled load-shedding within certain municipalities, to protect the electricity power system from overloading and causing nationwide blackout (R. S. Shrestha, 2010). Depending on the various regions, hours without grid energy of up to 12 hours have been experienced. In response to this power crisis, Nepal has been negotiating with countries such as China and India for possible investment in large-scale hydropower projects. A cross-border 400kV transmission line from India is also to be constructed to allow additional power imports which helps to deal with insufficient energy supply but reopens the argument of energy dependency (World Bank, 2018b).

Poor Operation & Financial Performance of the Energy Utility

Nepal Electricity Authority (NEA) is the governmental corporation in charge of the generation and distribution of electricity nationwide. High costs of their service due to annually rising costs of purchasing electricity from Independent Power Producers (IPPs), the importing of high-cost seasonal energy from India to cover national demand, and increased operation and maintenance costs of the national grid has caused the NEA to incur accumulated losses of $251 million and $60.9 million in 2015 alone (Ministry of Finance, 2016). The poor financial stance of the public utility has in turn caused a resonating effect of incompetence in the energy sector concerning the national capacity for generation and distribution of sustainable energy. The limitations in the planning component of energy management will be discussed further in the following segments, which will further highlight how this has affected the energy sector of Nepal.

Incapable Power Supply Systems & Energy Storage

Irrespective of the realized abundant resources of hydropower and the optimistic prospective to export electricity, Nepal has always been a net importer of electricity, due to its limited resources and capabilities involving in-house energy systems development and implementation. The amount of imported electricity has significantly doubled from 694 GWh in 2011 to 1,758 GWh in 2016 with an annual growth rate of 20.4%, which is an astounding finding. What is an even more alarming statistic is that the annual growth rate in energy generation by the NEA is 0.3%, which shows exactly how the situation of energy capacity of the country stands (Ministry of Finance, 2016).

While hydropower is the dominant alternative energy technology deployed throughout the country, storage-type plants make up for only 13% of the nation's total hydropower capacity (Asian Development Bank, 2013a). This is due to the popularity and widespread deployment of run-of-the-river hydropower systems, which although much cheaper to implement, operate, and maintain, lead to severe capacity shortages, particularly in peak demand periods over the dry winter period when the flow of water decreases drastically. The Government is currently attempting to address this specific issue with the prioritization of reservoir-based hydropower projects over the extensively deployed run-of-the-river systems whose energy generation is sporadic in nature due to its seasonal dependence.

2.7. Municipal Solid Waste Management in Nepal: A Policy Evaluation

The policy evaluation publication discussed in this section is from the Asian Development Bank (ADB) and focuses on the current status of Municipal Solid Waste (MSW) Management policies in Nepal and provides recommendations based on assessment and surveys carried out over 58 municipalities of the country in 2013. It discusses the key policy challenges faced regarding MSWM and provides improvements for more efficient solid waste management with regards to national policy. A need for more integrated solid waste management systems is discussed.

The evaluation object concerned is the MSW Management policy in Nepal and is carried out by an external producer organization, the Asian Development Bank (ADB). The consumers or users of this specific evaluation are each of the local municipality waste management administrating authorities.

The evaluation is ex post and formative in nature as it aims to determine the MSW generation and its composition in each of the municipalities and present the current status, practices, and issues of solid waste management (SWM) to adjust and optimize the policy and practices regarding SWM. It does so by identifying and evaluating the key policy challenges, effects reached as a result of the policy, and delivering recommendations for new policy formulating.

ADB's evaluation of the policy is a technical verification of the existing policy and its influences, assessing the goals and means of the national policy with regards to its effectiveness, efficiency, and responsiveness. This is carried out through the surveying of households, institutional and commercial outfits to measure the quantity and composition of wastes from the respective establishments. The following subsections aim to understand and dissect the MSWM policy evaluation, based on the policy evaluation theoretical framework developed by Coenen and Lulofs (2008).

2.7.1. Organization of The Evaluation

This subsection analyses MSWM in Nepal and explores potential improvement strategies and optimizations that could lead to more sustainable and effective waste management. This was a study carried out by ADB in 2013.

A. The Policy Tree & Causal Field Model

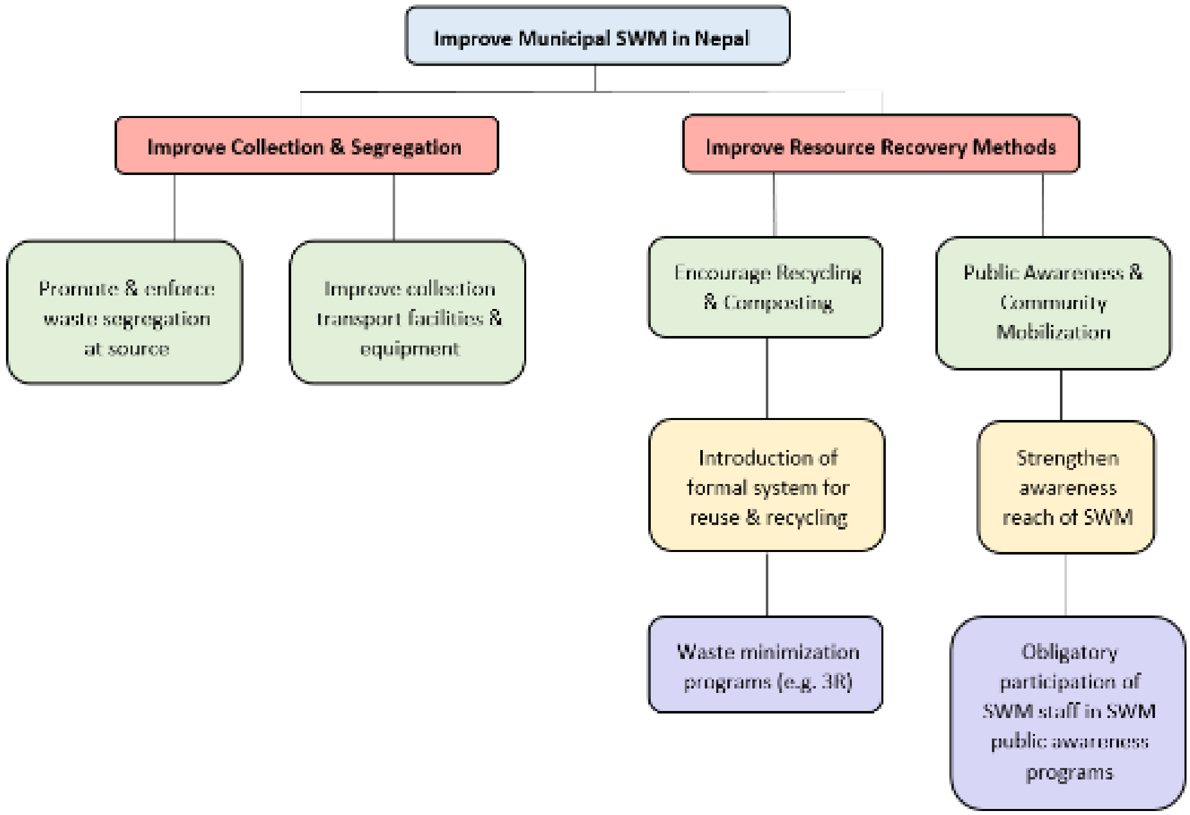


Fig.10 The Policy Goal Tree

From the rudimentary policy goal tree developed in figure 10, it can be acknowledged that the central goal is to improve and optimize MSWM in Nepal (shown in blue). Situations in the SWM policy field that contribute to the achievement of this primary goal are shown in red. Each of the sector goals which can promote these critical situations are shown in green. The sub-goals and the means/instruments through which these sub-goals can be attainable are represented in yellow and purple respectively.

A causal field model (figure 11) was also produced, in which situations and events which give rise to the undesirable case of Poor Municipal SWM (in red), are shown in blue with the effects of poor municipal SWM as a result represented in orange. It can also be noted that with a poor management system of solid municipal waste, increased build-up of waste is likely to occur, which in turn will result in a worse waste management infrastructure.

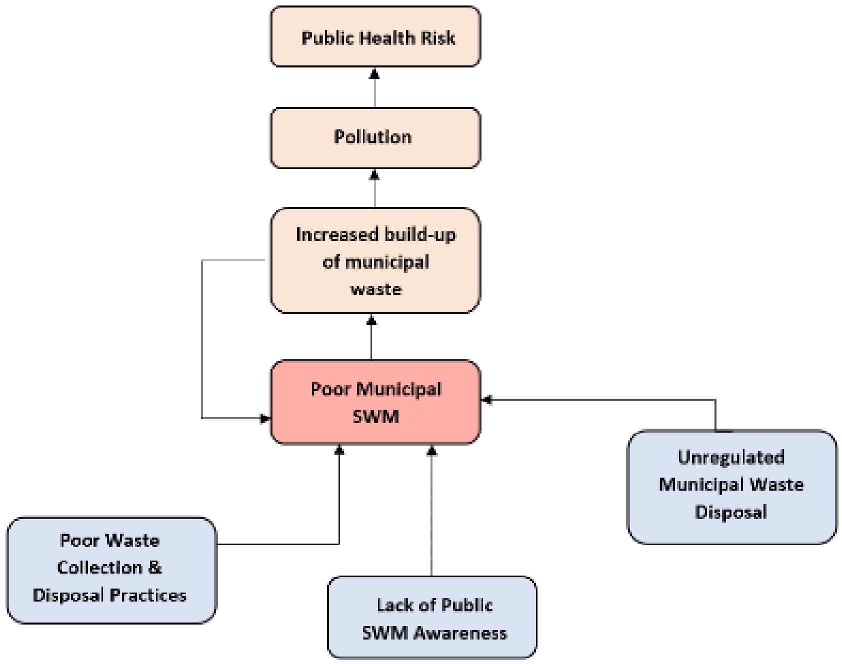


Fig.11 The Causal Field Model

B. Choice of Evaluation Criteria

The evaluation criteria in this case comprised of three parts:

- A sample survey of households to measure the amount and composition of household waste
- A sample survey of institutional and commercial establishments to measure the amount and composition of waste from these establishments
- A survey of the existing SWM system and financial, organizational, and institutional aspects of SWM.

The surveys carried out as part of the ADB study (Asian Development Bank, 2013b) covered all of the country's 58 municipalities with a sample size of 3,233 households, 627 institutions (offices and schools), and 627 commercial establishments (hotels, shops, restaurants) (Asian Development Bank, 2013b). Industry and health institutions were not covered by the evaluation surveys. The composition and quantity surveys categorized waste into eight categories which included organic waste, paper, plastics, rubber and leather, metals, glass, textile, and other inert materials.

C. Measure of Goal Attainment

For the study conducted, both urban and rural settings in the 58 municipalities were chosen stemming a much more thorough and precise average per capita waste generation rate within each municipality. Average daily waste generation rates were calculated for both households and institutional/commercial establishments.

Regarding per capita waste generation, the study made a direct correlation between the waste generation rate and economic status of the household, with higher expenditure resulting in the generation of more waste. It was also found that MSW composition measured by the study from the different areas depend on a number of factors including food habits, cultural traditions of inhabitants, lifestyles and economic status, consumer patterns, and of course, the climate. A large growth in MSW was recorded with the increasing use of plastics and packaging materials.

Out of all the surveyed households, it was found that only 30% of the households practiced segregation of waste at source, which meant that a staggering 70% of household waste went to municipality disposals in the form of mixed waste (Asian Development Bank, 2013b). Another finding was that citizens disposed of waste by unscientific composting, open burning, or simply throwing the waste into open space.

D. Influence of Policy

The idea of Reduce, Reuse, and Recycle (3R) has been seen to promote reduction in the amounts of municipal waste, encouraging segregation at source and thus saving costs for final disposal. Public awareness of SWM has grown but it is unclear whether this is a direct result of the study and its impact or if it is merely a change in societal behavior induced by other factors. Littering into open public spaces has drastically decreased as a result of waste minimization programs and initiatives like 3R.

A separate study also discovered that 82% of surveyed households would be prepared to pay a SWM fee if the overall service improved, which is another positive response from the public (Asian Development Bank, 2013b).

E. Level of Effectiveness

The policy has not yet fully achieved its desirable goal regarding optimal municipal SWM strategies, but it has contributed to numerous positive effects both on the household and commercial levels of waste minimization and has created a much stronger public awareness of SWM.

F. Recommendations & Presentation

The evaluation recommendations aim to address key policy challenges and emphasis on the development of precise policy, strategy, and guideline principles is at the forefront of ADB's suggestions. Other recommendations mentioned include the encouragement of public participation and consultation, strengthening capacities of municipalities, and integrated systems of SWM with segregation at source and efficient waste resource recovery practices encouraged.

3. Research Design

The research design of a project denotes an overall logical strategy constructed to answer possible research questions and is the foundation of the research methodology and its structure. This chapter discusses the activities undertaken to find answers to the research questions and to ultimately formulate recommendations for the public SWM sector within the municipality of Kathmandu.

3.1. Research Framework

The research framework, a key component of research design, is a schematic representation of the research objective. It consists of a 7-step approach to achieve the research objective.

i. **Step 1: Brief characterization of the objective of the research project**
The aim of this research is to form a recommendation to the municipal waste management authority of Kathmandu Metropolitan City for the improvement of solid waste management towards a more sustainable and effective approach.

ii. **Step 2: Declaration of the research object**
The research object in this research is the current practice of MSWM in Kathmandu Metropolitan City.

iii. **Step 3: Explanation of the nature of research perspective**
The conducted research suggests the concept of circularity as a sustainable solution to address inadequate operation of MSWM in Kathmandu. It will observe all of the relevant actors influencing the MSWM sector with the environmental, social, and economic aspects focal to the study. Opportunity for waste material utilization will be investigated from the perspective of a suitable and feasible waste-to-energy (WtE) technology for the MSWM sector to consider.

iv. **Step 4: Description of the sources of the research perspective**
The research uses scientific literature to construct a conceptual model. The theories that are to be used throughout the research are shown in the following table.

Table 2. Sources of the Research Perspective

Key Concepts	Theories & Documentation
Circular Solid Waste Management	Theory on Sustainable SWM
	Circular Economy Concept & Framework
	Theory on Waste Valorization
	Theory on Waste-to-Energy Technologies
	Information on Public Influence & Participation

v. **Step 5: Formulation of a schematic interpretation of the research framework**

The research framework is depicted in the following schematic diagram.

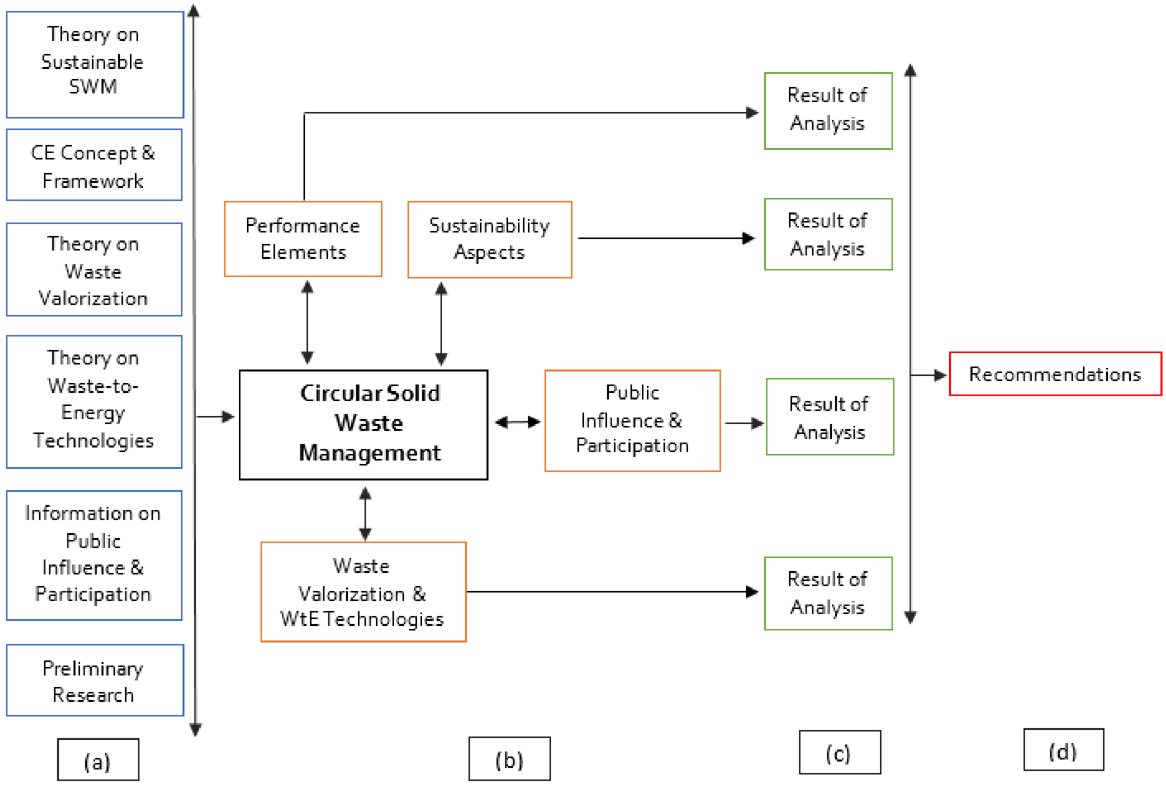


Fig.12 The Schematic Representation of the Research Framework

vi. **Step 6: Segmentation of the research framework**

The four stages of the research framework shown in figure 12 previously are mentioned below.

(a) Analysis of the theories and information explored on Sustainable SWM, Circular Economy, Waste Valorization, WtE Technologies, Public Influence and Participation with regards to SWM, and Preliminary Research to create a Circular SWM model

(b) The means of identification of the research object (i.e. Circular SWM), through assessment of the current MSWM practices in Kathmandu Metropolitan City

(c) Tackling the result of conducted analysis as a basis for the proposed recommendation

(d) Proposed recommendation for improving sustainability of MSWM in Kathmandu Metropolitan City

vii. **Step 7: Review of the model for any possible amendments**

3.2. Research Questions

Regarding this research, the principal question is mentioned below, along with consequent sub-questions that will help justify the overall aim of the research.

- **Given the current circumstances, to what extent can Circular Economy principles be integrated into the solid waste management strategy within Kathmandu Metropolitan City?**
    - (a) What are the current municipal Solid Waste Management practices in the city?
    - (b) What are the environmental impacts of the current municipal SWM practices mentioned?
    - (c) How have other cities succeeded to integrate circularity in their SWM and how can KMC draw inspiration from them?
    - (d) What is a feasible circular SWM framework for Kathmandu and how can it be implemented?
    - (e) What are the challenges for integrating CE principles in SWM in Kathmandu?

3.3. Research Concept

i. **Solid Waste:** Solid waste refers to discarded non- liquid materials as resultant by-products of day-today human activities. It consists of organic waste (e.g. food), combustibles (e.g. paper, wood), non-combustibles (e.g. metal, glass), bulky waste (e.g. tyres, tree branches), hazardous waste (e.g. oil, battery acid), construction waste (e.g. rubble, concrete), etc. (European Commission, 1994).

ii. **Solid Waste Management:** Solid Waste Management involves the handling of solid waste. It includes the collection, transportation, treatment, and disposal of solid waste.

iii. **Sustainability:** The concept of sustainability is such that the needs of future generations are not compromised in the development to cater for the needs of the present (Brundtland, 1987).

iv. **Sustainable Solid Waste Management:** Sustainable solid waste management is such system that is environmentally undamaging, economically feasible, and socially acceptable.

v. **Circular Economy:** The concept of a circular economy refers to an economy that is restorative by design. It aims to promote the use of renewable energy, the minimization of waste, and process inefficiencies, thus building resilience through planned closed-loop processes throughout all sectors in society (Ellen MacArthur Foundation, 2013).

vi. **Circular Solid Waste Management:** Circular SWM is the management of solid waste with the adoption of circular economy principles (Ellen MacArthur Foundation, 2013).

vii. **Waste Valorization:** The concept of waste valorization refers to any industrial processing activity intended to reuse, recycle, or compost from waste material. It usually involves the processing and utilization of waste or by-products into raw materials or energy sources. The types of wastes expended in valorization processes are usually non-damaging to health and the environment (Idowu, Capaldi, Zu, & Gupta, 2013).

viii. **Waste-to-Energy:** WtE is the process of energy recovery through the generation of energy in the form of electricity or heat from the management and utilization of waste.

3.4. Research Strategy

A research strategy is the approach a researcher exercises to collect and analyze relevant material in order to obtain conclusive answers for the research questions devised. This research uses a single case study approach (municipality of Kathmandu) which will be analyzed in depth embodying the general research strategy. It incorporates a desk research approach to identify applicable sources of information and data to aid the investigation.

3.4.1. Research Unit

The research unit for this research is the municipal SWM, with the observation unit being the framework for SWM. Kathmandu Metropolitan City will function as the case study of this research.

3.4.2. Research Unit Data Sources

To ultimately analyze opportunities for integration of CE principles in Kathmandu Metropolitan City's SWM, several stakeholders influencing the MSWM of Kathmandu and its future development into a much more sustainable model were identified:

- National & local government authorities
- Development partners
- Private sector organizations
- NGOs & INGOs
- Community-based organizations (CBOs)
- Citizens

3.4.3. Research Boundary

The research boundary outlines the limitation of the study conducted and its reliability. By setting the research boundary, a more feasible research plan can be designed within the limited timeframe. The boundary set for this specific research is as follows:

- The MSW covered in this study is limited to household and commercial wastes excluding waste generated from gardens, public parks, street sweeping, and hospital medical waste.
- As data on MSW and its management in the case of KMC is very limited and seldom updated, this study can only utilize the accessible data available to the researcher.
- The environmental opportunity is discussed from the perspective of feasibility of WtE technologies applicable for the case of Kathmandu Metropolitan City.

3.5. Research Material

Regarding this research, secondary data is to be obtained from reputable sources, researchers who have been carrying out research related to the waste management sector of Kathmandu. Various academic literature available online will also be used as support for the research conducted to further justify analysis of the collected data.

3.6. Data Analysis

Data analysis in this research involves a qualitative methodology, aiming to provide a thorough understanding of the subject in question. During the initial stages of research, exploration into various relevant information available regarding the waste management sector within Nepal, and more specifically Kathmandu, will be carried out with a qualitative approach. The findings in this initial stage will provide a foundation for the analysis phase, in which recommendations for the sustainable operation of MSWM in Kathmandu will be formulated.

Table 3. Method of Data Analysis

Research Sub-Question	Data/Information Required to Answer the Question	Method of Analysis
(a), (b), (d), (e)	History of MSWM in Nepal and Kathmandu	Qualitative: analyzing how the MSWM sector has operated overtime
(a), (d), (e)	Regulatory Framework in the MSWM sector	Qualitative: as input for analyzing the actors' political, economic, social and cultural aspects concerning MSWM
(a), (b), (d), (e)	Available management systems and technologies in the MSWM sector	Qualitative: as input for analysis of current management systems and applied technologies in Kathmandu regarding MSW
(a), (d), (e)	Information regarding the actors and stakeholders in the MSWM sector	Qualitative: as input for analyzing the roles of actors in the MSWM
(a), (d), (e)	Information about the roles of each actor and their respective abilities to conduct their jobs	Qualitative: analyzing obligations, responsibilities, and degrees of participation of actors to transition towards a sustainable MSWM system
(c), (d), (e)	Information about WtE technologies and successful CE integration into SWM of other countries	Qualitative: analyzing and reviewing various WtE technologies and cases of CE integration in the SWM systems of other countries to serve as inspiration for KMC's recommended MSWM

3.7. Research Ethics

As this research does not directly involve humans or animals, ethical sensitivities are not entirely relevant for data gathering and analysis. However, ethical considerations with regards to the purpose of the study and what it aims to achieve, are relevant, as this study may have an impact on actors/institutions observed. Since the study aims to contribute to sustainable development in the municipal waste management sector, the principles of ethical research are respected and obeyed throughout every aspect of research including data gathering, analysis, and reporting. The principles of ethical research comprise of respecting autonomy, non-maleficence, beneficence, justice, and fidelity (L Beauchamp & F Childress, 1979).

4. Findings & Discussion

This chapter includes an overview of the current conditions of SWM in Kathmandu according to the information and findings gathered during the data collection phase. Various challenges faced with regards to proper waste management and possible barriers restricting circular SWM in the city are investigated, in hope to propose an appropriate and feasible framework to integrate CE in the SWM sector of Kathmandu.

4.1. The Condition of the Studied Area

Before discussing and reviewing the current conditions and practices of SWM in Kathmandu Metropolitan City, an overview of the city will be presented in order to provide background information for a better insight into how and why the SWM sector operates the way it does presently.

Kathmandu Valley is the administrative center of Nepal and consists of three districts, five municipalities, and 99 village development committees (VDC) (UN Habitat, 2015). It lies between latitudes 27032’13” and 27049’10” north and longitudes 85011’13” and 85031’38” east. The three districts which make up KV are the cities of Kathmandu, Lalitpur, and Bhaktapur, which comprise of five municipalities; Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City, Kirtipur Municipality, Bhaktapur Municipality, and the Madhyapur Thimi Municipality, and 99 VDC’s which can be seen in figure 13. The valley accounts for an area of 167 hectares (1.67 sq. km) standing at an elevation of approximately 1,400m holding approximately 2.5 million inhabitants, out of which 975,453 people live in KMC (Central Bureau of Statistics, 2012).

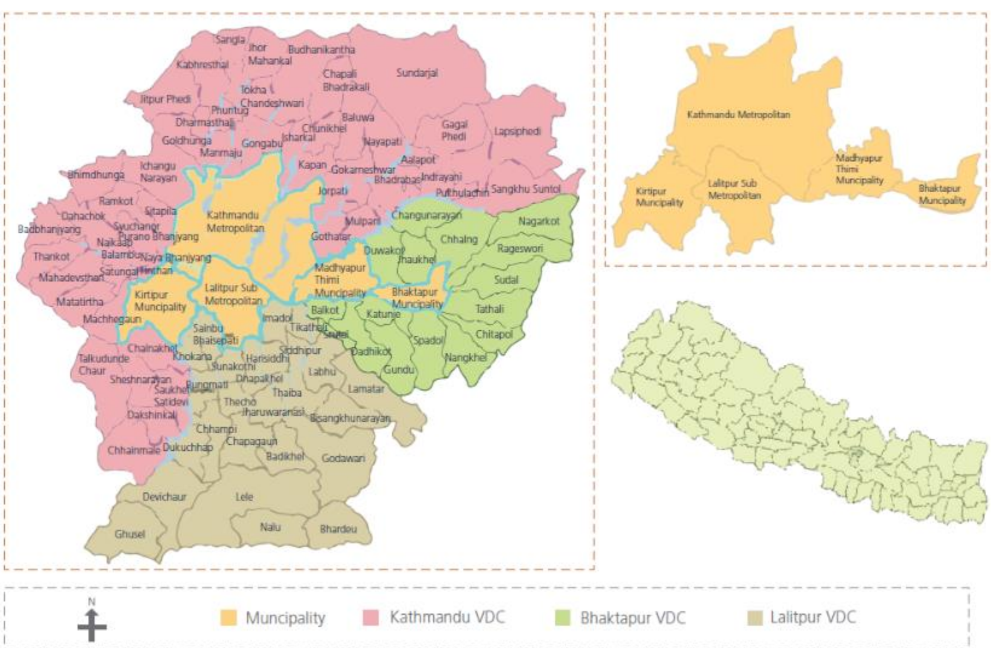


Fig.13 Maps of Kathmandu Valley *(UN Habitat, 2015)*

Kathmandu Valley has undergone rapid urbanization in recent years with the highest annual rate of urbanization in the Asia Pacific region of 6.6% during the 1990s, with the most recent 2011 census indicating that KV contained 32.4% of the total urban population of the entire country (UN Habitat, 2015). Out of all the districts within KV, Kathmandu had the highest annual growth rate per annum of 4.78% in 2011, which gives an idea of the congestion and population density within the city.

4.2. Current Status of Municipal SWM in KMC

4.2.1. Current Situation Overview

Concerning the SWM practice in KMC, various key stakeholders were identified as having significant influence on the daily operation of the sector. These include the residents of the city, the government, private sector organizations, and NGOs.

Kathmandu has a semi-formal SWM sector arrangement in which each of its 35 wards is responsible for the managing and organizing of respective waste collection and disposal (Dangi, Schoenberger, & Boland, 2015). The three main cities that make up Kathmandu Valley: *Kathmandu, Lalitpur, and Bhaktapur* have independent SWM responsibilities accepted by their respective local authorities. Historically, the municipalities employed cleaners known as "kuchikars", which in Nepalese means 'cleaners', who were responsible for the collection and disposal of public solid waste and used tractors to dispose the collected waste along the riverbanks within the city (Pokhrel & Viraraghavan, 2005). From the public's perspective, it implied that it was no longer their responsibility for the management of their solid waste, thus discouraging the traditional practice of community participation in waste management practices within the valley (Pokhrel & Viraraghavan, 2005). This public negligence and rapid growth in urban population have certainly not made successful management of the city's solid waste a straightforward task.

Currently, the national budget allocated for environmental management and public health is considerably low and the issue concerning land availability for the siting of landfilling of MSW within the valley has been highlighted for over two decades (Ministry of Urban Development, 2015). As a result, a lot of the MSW ends up alongside the rivers flowing through KMC, posing numerous threats to the environment and public health.

Although there has been an increase in waste collection due to the involvement of the private sector and INGO funding and the willingness of the public to cooperate with waste separation at source, the government's incapacity for sector funding and modelling a plan for a more efficient disposal system has restricted any real progression in this area of development (R. Alam, Chowdhury, Hasan, Karanjit, & Shrestha, 2008). As a consequence, raw solid waste from the dumping sites regularly come in contact with river water, leading to irreversible river contamination affecting the quality of the water (R. Alam et al., 2008).

Vehicles used commonly for the transportation and final disposal of MSW include rickshaws and carts for primary collection, tractors for secondary collection and transport, and dump trucks for the transport of waste to disposal sites.

Official sites dedicated for treatment facilities and sanitary landfills are yet to be acknowledged by municipality authorities, with the majority of waste being currently disposed crudely in unorganized dumping sites, posing a real threat to the environment and increasing the chances of public health risks (Asian Development Bank, 2013b). Currently, the majority of municipalities of the entire Kathmandu Valley utilize a single landfill site in Sisdol, located about 28km from central Kathmandu, which is critically running out of its capacity to absorb any more waste, posing a very severe problem (R. Singh, Yabar, Nozaki, & Rakwal, 2015). Figure 14 shows the existing scenario of final waste disposal practiced by the majority of municipalities of Nepal, including Kathmandu Metropolitan City.

Fig.14 MSW Piled up at Teku Transfer Station in Kathmandu *(Asian Development Bank, 2013b)*

KMC was initially established in 1919 to manage solid waste and sanitation activities within the municipal territory of the Kathmandu district city within KV (Ministry of Urban Development, 2015). Since then, it has taken on the responsibility of managing street sweeping, municipal waste collection, its transportation, and final disposal. Currently, KMC is encountering a number of concerns and challenges including, for example, the collection of rising quantities of unsegregated waste and the lack of awareness and practice of 3R strategies throughout the various levels in society (Asian Development Bank, 2013b).

4.2.2. Sector Structure

As mentioned in the *Local Self Governance Act, 1999* (Government of Nepal, 1999), KMC is solely responsible for all SWM activities within its jurisdiction. The Ministry of Federal Affairs and Local Development (MOFALD) is accountable for the formulation, implementation, monitoring and review of all policies and plans concerning sanitation and sewerage, the Ministry of Urban Development (MOUD) in charge of sanitation and drainage within the city, and the Solid Waste Management Technical Support Centre (SWMTSC) functions as a monitoring mechanism for MSWM, as outlined in the *Government of Nepal (Allocation of Business) Rules, 2012* (Government of Nepal, 2012).

4.2.3. Policy & Legal Arrangement

Concerning matters involving MSWM, the *Solid Waste Management National Policy, 1996* (Ministry of Local Development, 1996) is the primary policy document. The policy aims to promote full cooperation amongst members of society including citizens, industry, and NGOs for the reduction of detrimental effects on the environment and public health caused by the mismanagement of solid waste. The objectives outlined in section 2 of the document are as follows:

- To simplify and improve the efficiency of the management of solid waste
- To reduce environmental pollution and damaging effects on public health resulting from the build-up of solid waste
- To initiate the idea of utilizing solid waste as a valuable resource when possible
- To privatize the management activity of solid waste
- To raise awareness and change public perception of solid waste and sanitation

In addition to the primary national policy document, there also exists various rules and regulations related to the solid waste management for KMC that further extend and support the guidelines set by the overlooking policy. Each of these documents contain specific guidelines and directives for all stakeholders having a responsibility for solid waste management in the country. These include the following:

- Solid Waste Management Rules, 2013
- Solid Waste Management Act, 2011
- Local Self-Governance Act, 1999
- Environment Protection Act, 1997

4.2.4. The Solid Waste Management Elements in KMC

This section assesses the findings of the SWM system elements in KMC based on the ISWM framework illustrated in figure 2. These elements consist of waste generation and its composition, collection and transportation, treatment and disposal, and post-treatment components such as recycling, material recovery, and reutilization.

Municipal Solid Waste Generation & Composition

When forming a SWM system, the total amount of waste and composition of the generated waste are critical factors that need to be considered. Both of these elements may be dependent on variables such as population growth, urbanization, varying lifestyles, economic activities, and are sometimes also influenced by the season (Asian Development Bank, 2013b). The total MSW generation of KMC includes two categories of solid waste, which are the residential waste generated by households, and non-residential waste contributed by commercial (hotels, businesses and enterprises) and institutional (offices, schools, and colleges) waste streams (Asian Development Bank, 2013b). A total of 466 tonnes of MSW was recorded to be generated in KMC, with 233 tonnes contributed by households, 203.5 tonnes from the commercial sector, and 29.5 tonnes making up the institutional waste (Asian Development Bank, 2013b). The waste generated per capita was calculated to be 0.23kg per person per day (Asian Development Bank, 2013b).

The characteristic or composition of the solid waste generated is equally as important as the quantity of waste observed (Ministry of Urban Development, 2015). The amounts of various types of materials in the waste stream need to be noted and understood, as each waste component has to be dealt with separately and may require unique treatment (Ministry of Urban Development, 2015). Essentially, MSW is comprised of two primary waste categories, which are organics and inorganics. Organic waste is composed of any material that is of biological origin and is biodegradable, meaning that it can be broken into carbon dioxide, methane, or simple organic molecules (City of Signal Hill, 2016). Examples of such waste include food waste, non-hazardous wood waste, and green or garden waste (City of Signal Hill, 2016). Inorganic waste can be segregated into paper, plastics, glass, textile, metals, rubber, leather, and inert materials accumulated through construction activity (Ministry of Urban Development, 2015). Table 4 and figure 15 provide a representation of the overall MSW generation and composition in Kathmandu Metropolitan City. The individual waste compositions of household waste, institutional waste, and commercial waste can be found in Appendix B.

Table 4. MSW Generation & Composition of KMC *(Asian Development Bank, 2013b)*

MSW Generation	Weight per capita (kg/cap/day)	0.23
	Weight generated (ton/day)	466.14
MSW Composition (%)	Organic	43.32
	Plastic	21.60
	Paper	25.41
	Glass	2.66
	Metals	1.83
	Textiles	2.77
	Rubber & Leather	0.75
	Others (i.e. Inert Materials)	1.65

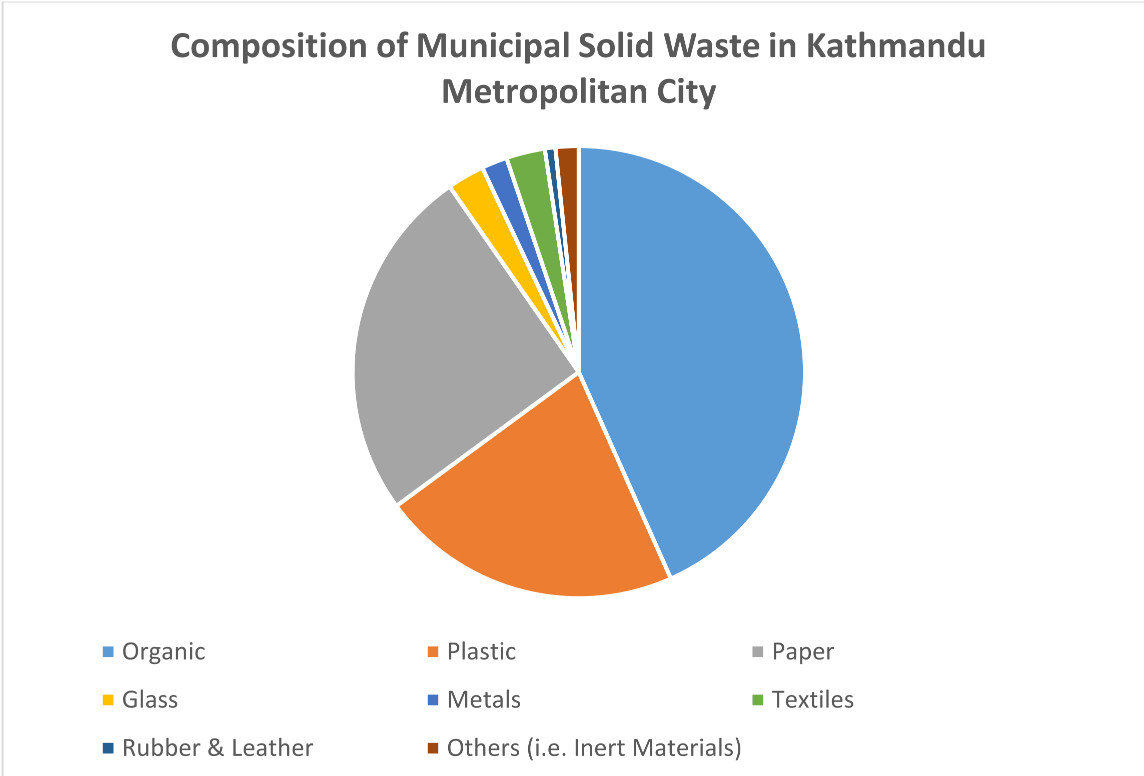


Fig.15 Total MSW Composition in KMC *(Asian Development Bank, 2013b)*

It is evident from figure 15 that organic matter (43.32%) is the most notable waste type generated, followed by paper (25.41%), plastics (21.60%), glass (2.66%), and textiles (2.77%). Metals, rubber and leather, and other inert materials were less significant in comparison, each accounting for under 2%. It is established in the study carried out by ADB (Asian Development Bank, 2013b) that the dominant organic content provides an indication that regular and efficient collection, separation, and treatment of biological waste is critical for sustainable waste management to flourish throughout the city. The large fraction of waste being organic in nature also presents potential for a promising economic opportunity regarding bio-waste resource recovery and reutilization.

The rest of the inorganic waste generated (55.03%) excluding the inert material waste (1.65%), are either recyclable or reusable, highlighting the importance of embedding waste valorization techniques into the waste management of the city. More notably, it was observed by the researcher that the composition in MSW in KMC has drastically changed over the years with the increasingly widespread use of plastics and packaging materials, further reinstating the urgency and importance of 3R and waste valorization within the sector. The need for acute waste management concerning plastics can be felt from the observing a continual rise in the waste fraction of plastics from 5.4% of the overall MSW generated in 2005 (Dangi, Urynowicz, Gerow, & Thapa, 2008) to 12% in 2007 (Dangi, Pretz, Urynowicz, Gerow, & Reddy, 2011) and 21.60% in 2013 (Asian Development Bank, 2013b).

Municipal Solid Waste Collection & Transportation

The collection and transportation of solid waste is a crucial component of a city's overall management of MSW. An efficient and methodically planned waste collection and transfer system from source ultimately to the treatment facility can directly determine the success and sustainability of the sector's operation. In the case of KMC, three types of collection systems are employed; with *primary collection* referring to the placing of solid waste into personal refuse bins, *secondary collection* involving the collection of solid waste from refuse bins or other primary sites to be transported to either a transfer station, dumping site, or landfill, and finally *direct collection,* employing collection personnel to conduct door to door collection of solid waste prior to its transfer for final disposal (R. Alam et al., 2008). Although the majority of the responsibility of waste collection and transportation lies with the KMC municipality, there exists collaboration with private sector organizations (PSOs) and NGOs to collect solid waste throughout the various wards of the city(Ministry of Urban Development, 2015).

In an effort to address many of the city's MSW problems, the Government of Nepal has initiated the Integrated Solid Waste Management Project in March 2018, contracting two private companies to the management of MSW in Kathmandu Valley (The Kathmandu Post, 2018a). *'Nepwaste'*, a Finnish joint venture and *'Clean Valley Company'*, a Nepali-Indian joint venture has been granted the responsibility to overlook the management of solid waste throughout Kathmandu for the next 20 years, with a preliminary public-private partnership agreement worth $50 million confirmed (The Kathmandu Post, 2018a). Although the commercial operation of the MSWM sector remains to be assessed, it provides a great deal of optimism to finally rectify the unsystematic and ineffective system that has been employed for the past few decades.

From the study carried out by ADB in 2013 (Asian Development Bank, 2013b), it was recorded that out of the 466.14 tonnes of MSW generated daily throughout the city, an estimate of 405 tonnes was successfully collected, indicating a collection efficiency of 86.88%. This, however, as stated by ADB, could be an overestimate by the municipality due to the lack of proper scientific logger systems (Asian Development Bank, 2013b). An absence of a survey or study on waste collection within KMC, the waste generation rate, its density, transportation, and storage, could also be the reason for unrealistic estimation, which has indeed compromised the efficiency and effectiveness of SWM in the city. It was recorded that the municipality had employed a total of 1,100 people in the SWM sector for KMC in 2014, with 828 kuchikars (sweepers) employed to clean the streets and handle solid waste throughout the city and 135 drivers involved in the collection and transportation of solid waste to dumpsites or the Sisdol landfill site (Ministry of Urban Development, 2015). Table 5 below shows the human resources involved in the SWM sector of KMC.

Table 5. List of Personnel Engaged in the SWM Sector of KMC

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	**1,111**

Transportation of solid waste is another vital component in SWM to ensure the transfer of waste from source to treatment. The SWM Act 2011 (Government of Nepal, 2011) has allocated responsibility with regards to the transportation of MSW to the municipality, with private organizations involved in the city's SWM activities also assisting them. Table 6 shows the major types and number of vehicles involved in the collection and transportation of solid waste in the city, although rickshaws, carts, and trailer tractors are still widely used to collect waste throughout the city as well. Informal sectors involved in solid waste collection in the city also exist in the form of scavengers and nomadic waste buyers who collect plastic, metal, glass, and other salvageable material from households. Generally, rickshaws and carts are used for primary collection, tractor trailers for secondary collection and transport, and container dump trucks utilized for the transfer of waste to disposal sites (Asian Development Bank, 2013b).

Table 6. List of Vehicles Involved in SWM Collection & Transportation in KMC *(Nepwaste Project Report, 2018)*

	Vehicle Types	Total	No. of functional vehicles in use	No. of non-functional vehicles
1	Container Truck	17	16	1
2	Tipper	23	20	3
3	Compactor	12	5	7
4	Dumper Placer	12	3	9
5	Hermetic Self-Discharging Garbage Truck	50	33	17
6	Road sweeper	5	1	4
7	Self-discharging & Loading Garbage Truck	30	3	27
8	Backhoe loader	3	1	2

According to rule 7 of the SWM Rules 2013 (MoEFCC, 2016), issued by the Government of Nepal, the following conditions for transportation of solid waste is to be exercised:

a) Solid waste should not be visible, should not fall out, and no seepage of liquid materials should be made
b) Should be no leach or odor released by the solid waste
c) Solid waste should be able to be loaded and unloaded with ease
d) Transportation of solid waste should be conducive to the road capacity and conditions

However, the reality of the situation is far from the preferred scenario laid out by the SWM rules 2013 document, with mass accumulation of MSW piled alongside roads, sometimes unattended to for long periods of time, especially in the monsoon season (The Rising Nepal, 2018). Designated dumpsites are damaged, and transportation of waste comes to a complete halt during these periods, leaving large volumes of waste piled up alongside roads as can be seen in figure 16.

Fig.16 Solid Waste Accumulation Left Unattended in Kathmandu
Source: (Hada, 2018)

Due to the limited types and insufficient number of vehicles available to the municipality, collection of the accumulated waste is sometimes executed inadequately and in contradiction to the SWM rules imposed by the government (Ministry of Urban Development, 2015). Collection, sweeping, and city cleaning is only carried out on a daily basis in market areas, along major roads, and very few residential areas, with many areas tended to sporadically from twice a week to twice a month, or are not dealt with at all in some instances (Asian Development Bank, 2013b).

The images presented in figure 17 (a&b) show the manner in which much of the accumulated waste piles in various parts of the city are collected and transferred onto the container trucks. It can be noticed that there is a limited space onboard the trucks to hold the usually high volumes of waste, which can be due to a concerning combination of the irregularity of collection and critically high solid waste generation rates.

(a)

(b)

Fig.17 (a) A Backhoe Loader Transfers Solid Waste Build-up from the Street onto a Container Truck in Dallu, Kathmandu.
(b) An Exposed Container Truck at Overcapacity Leaves the Area Where Waste Will Accumulate Once Again. Source: *(Shrestha, 2018)*

To improve and promote systematic waste collection and transportation, waste segregation at source and arrangement of waste containers for households is essential. Source Segregation (SS) and collection has been established by Geisler (2014) as an essential component in the overall waste management chain to drive the practice of 3R, but it can also have a major economic impact by influencing the potential energy gain from the separation of organic content from MSW. The separation of organic materials at the point of collection can lead to more homogenous and potentially higher quality waste streams for energy recovery utilization (Geisler, 2014).

However, in the case of KMC, waste that could be segregated at source is often mixed again during collection and transport due to the lack of any consistent or systematic collection and treatment methods (Asian Development Bank, 2013b). Uncollected waste is often openly disposed of into public spaces or into the rivers running throughout the city, and in some cases, open burning of waste is also performed, posing serious risks to both human health and the environment (Ministry of Urban Development, 2015). It has been reported that the government has recently called for a ban on the practice of open burning of waste to mitigate air pollution (The Kathmandu Post, 2018b), however whether or not it will be implemented remains to be seen. Such extreme practices of disposal in society have not made the already difficult task of collection and transport of solid waste in KMC straightforward.

The complete absence of any provision of waste containers or dustbins for households by the municipality has also given rise to the issues regarding waste collection and transport highlighted above. According to Section 8 of the SWM Act 2011, the municipality may arrange separate containers for households to be collected at different 'toles' or neighborhoods in order to have a systematic, regular, and orderly collection of solid waste (Government of Nepal, 2011). There are still no official collection zones or waste containers arranged by the municipality to date, with hazardous solid waste continuing to be accumulated in some public spaces as was shown by figure 16, thereby posing serious concern to the wellbeing of the city's environment, animals, and the population (Ministry of Urban Development, 2015).

Municipal Solid Waste, Transfer Station, Treatment & Final Disposal

Teku Transfer Station

The bulk of the solid waste collected by the relatively small capacity vehicles cannot be transported over long distances. For this reason, the waste is taken first to KMC's only transfer station in Teku, located in the southwest region of KMC, and only then is it transferred to the Sisdol landfill site in compactors. The Teku transfer station covers a 1.5 ha area (R. Alam et al., 2008) and is surrounded by residential area and comprises of an open space having a capacity to hold 10,000 tonnes of MSW (Ministry of Urban Development, 2015).

At the transfer station, collected waste is unloaded onto a concrete ground, sorted out by scavengers, scooped up with excavators, and placed into large container trucks to be transported to the Sisdol landfill. The station was initially built with an infrastructure to segregate incoming MSW streams and compost organic waste, however, managerial difficulties have prevented the commencement of both practices (Ministry of Urban Development, 2015). Section 11 of the SWM Act 2011 states that a transfer station must be set up to manage MSW collected whilst taking into consideration the wellbeing of the environment and public health, preventing any adverse effects from the waste accumulation at the site (Government of Nepal, 2011). However, as mentioned previously, particularly during the monsoon season when the Sisdol landfill site is susceptible to closure, the condition of the Teku transfer station becomes critically severe. It has been confirmed in the environment audit report of the SWM of KMC carried out in 2015, that the landfill site closed for a total of 51 days between March 2013 and March 2015 due to poor road conditions during the monsoon (Ministry of Urban Development, 2015). Substantial volumes of MSW is amassed at the transfer station for several days as a result (see figure 14), causing respiratory and other health problems to the locale, and environmental degradation in the surrounding area (Ministry of Urban Development, 2015).

Final Disposal at Sisdol Landfill

Final disposal of waste is generally the final step in SWM and in the case of KMC, the gathered MSW is ultimately transferred to the Sisdol landfill site. The landfill area in its entirety covers a total of 15 ha, with the actual landfill site taking up an area of approximately 2 ha. The site consists of two landfill basins, the first of which is *11,200* m^2 in area and having a capacity of *166,085* m^3, and the second having an area of *9,501* m^2 and a capacity of *108,910* m^3 (Dept. of Environmental Science and Engineering, 2012). About 600 tonnes of MSW is transported and dumped onto the landfill site from the transfer station per day by up to 30 container trucks. The waste is compacted with soil excavated from the hills nearby utilized to cover the waste and chemicals such as phenol, cintrol, and novan are also applied to remove odor from the landfill site (Dept. of Environmental Science and Engineering, 2012).

The site was initially designed to be a semi-aerobic sanitary landfill[6] to monitor and prevent leachate[7] from contaminating the soil as well as ground and surface water but has not entirely fulfilled that criteria. It was observed that the covering of waste with soil is not carried out on a regular basis.

[6] *Sanitary landfills* are designated sites where waste is isolated from the environment until it is treated. A semi-aerobic sanitary landfill is one which is designed with a leachate collecting piping system underneath the landfill to permit air flow in and out from the solid waste, allowing a natural supply of oxygen to the decomposition microorganisms for the decomposition of waste (Hamidi & Hosseini, 2012).

[7] *'Leachate'* is the residual liquid that drains from landfill waste, formed by rainwater washing out the degraded waste material. It contains both dissolved and suspended material, in the form of organic and inorganic chemicals, heavy metals, and harmful pathogens that can contaminate soil and groundwater (Osterath, 2010).

This has exposed the surrounding environment to highly toxic air pollution, as emissions of landfill gas generally comprise of approximately 50% methane, which is roughly 30 times more potent than carbon dioxide as a heat-trapping gas, contributing greatly to the issues of climate change and global warming (Kelly, 2014).

As mentioned previously, transportation of waste to the landfill site is held up during the monsoon season, when the site becomes extremely muddy and difficult to manage. The absence of systematic inspection and maintenance of the landfill site system has also hindered the effective operation of the site with high risks of blockages in the leachate collecting piping system and an alarming build-up of MSW (Dept. of Environmental Science and Engineering, 2012). The leachate that builds up over time as a result, is hazardous and highly acidic, posing a major threat to the condition of the surrounding soil and groundwater sources. Also, as the basin area of the site is not confined, livestock frequently end up grazing and feeding upon the hazardous waste (Dept. of Environmental Science and Engineering, 2012). The image in figure 18 shows the unguarded landfill site with cattle feeding on the collected waste.

Fig.18 MSW Accumulation at the Sisdol Landfill Site with Some Cattle Seen Feeding on the Hazardous Waste
Source: *(Pandey, 2016)*

Although most of the waste collected and transferred daily is organic and degradable, which is ideal for composting, the lack of a reliable and effective waste segregation system throughout the entire waste supply chain has led to the dumping and an uncontainable build-up of all types of wastes in the landfill. This has brought up the concern of limited exploitable land availability, with the continual overdependence and excessive use of the Sisdol landfill site, firstly whose intended design life period has long since expired since being established in 2005 (Ministry of Urban Development, 2015), and is also rapidly running out of capacity (Dept. of Environmental Science and Engineering, 2012).

This substantial dumping of MSW at the site has created political unrest as well, with frequent local protests against the lack of proper management, unavailability of required waste treatment equipment and safety gear for the workers of the landfill, and unsanitary methods of final disposal. The government had recently identified Banchare Danda as an alternative for a potential landfill site about 2km west from the Sisdol site (Ministry of Urban Development, 2015), but this plan seems to have stalled due to the excessive cost of constructing the landfill infrastructure (Ojha, 2018).

Recycling, Resource Recovery & Reutilization

Resource recovery from the management perspective of MSW has the capacity to reduce environmental, financial, and social burdens on the municipality and can even unlock new revenue streams, thereby building resiliency of the city, which is at the core of the concept of CE discussed in Section 2.2. It can be observed that out of the total MSW generated daily in KMC (see table 3), *43.32%* is that of organic waste, which can be managed by segregation and composting at source, and *55.03%* is in the form of plastic, paper, glass, metals, textiles, rubber, and leather, all of which are either recyclable or reusable. Approximately *35%* household waste is recyclable of reusable, with a larger proportion of this type of waste (*53%*) produced by the institutional and commercial sectors. Although the significant fraction of re-utilizable waste indicates a promising opportunity of 3R practices and all the benefits that are associated with it, there are no formal systems or directives for either composting nor reusing or recycling established within the city (Ministry of Urban Development, 2015).

As a result, the majority of solid waste recycling in KMC is undertaken by non-governmental groups comprising of the private sector, schools and communities, NGOs, and informal groups consisting of waste scavengers and solid waste collectors, whose roles in the overall waste material flow of KMC can be seen in figure 19 (Ministry of Urban Development, 2015). For example, resource recovery, mainly of plastic materials, is carried out by private operators. However, these private sector waste management companies operate without any formal coordination or service agreement with the public authorities, and as per the SWM Act 2011, they do not fit in the official MSWM of KMC, as the responsibility of managing MSW is solely the municipality's (Ministry of Urban Development, 2015).

Wandering waste collectors and landfill scavengers also play a major role in the collection of the city's recyclable waste. The itinerant waste collectors in particular, travel from door to door on bicycles, gathering paper, metals, and glass from households (Gautam, 2011). These informal actors sort, clean and sell recyclable waste material to various scrap dealers throughout the city, who then export the waste to India to be recycled (van Beukering and Badrinath, 1995). Most of the recyclable scrap waste like paper, iron, and glass is recycled or reused in Nepal, with waste material such as plastics, tin, lead, and textiles are usually exported to India by the scrap dealers (Luitel & Khanal, 2010).

Figure 19 shows the waste supply chain and material flow of the generated MSW in KMC, emphasizing a lack of formal recycling and reutilization facilities in the sector and most of the waste ending up at the Sisdol landfill site. There is also a complete absence of waste segregation from the municipality, with landfill scavengers and informal waste workers mainly involved in waste separation, usually at transfer station or the landfill site.

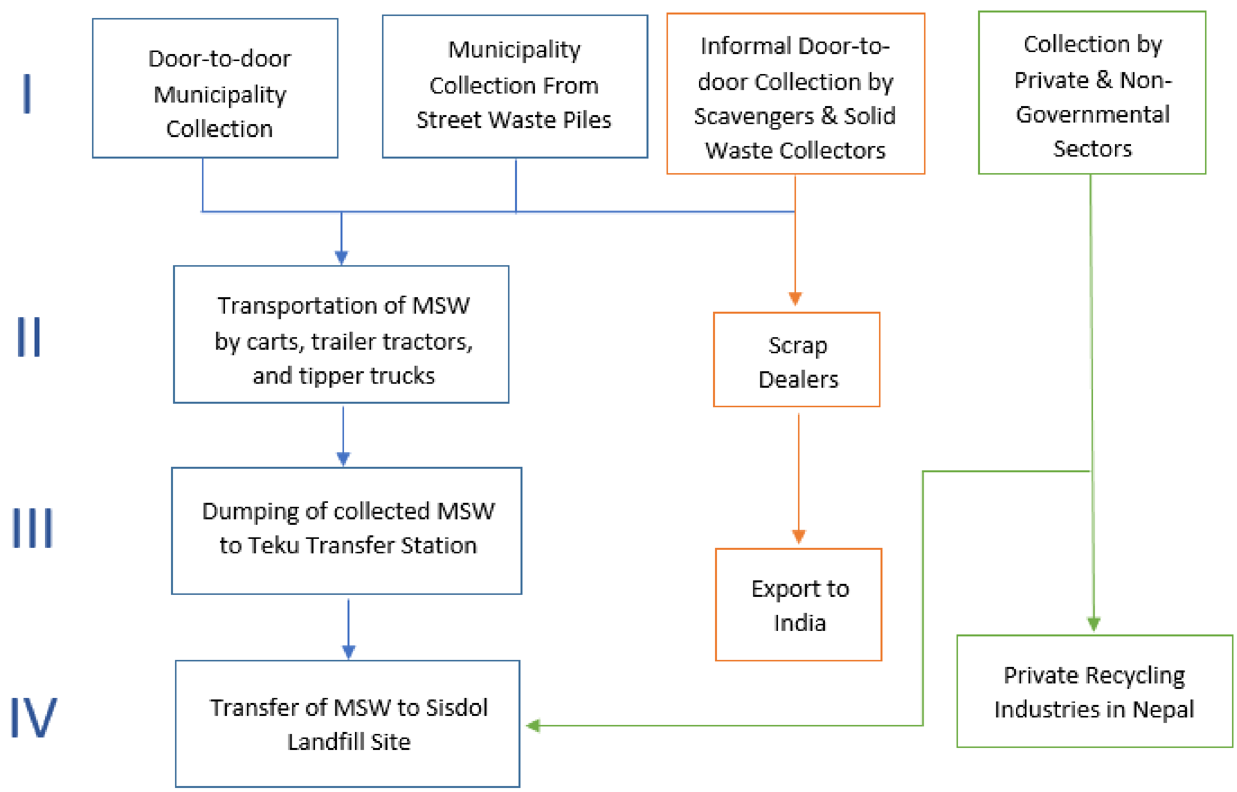


Fig.19 The MSW Supply Chain Showing the Material Flow of Generated MSW in KMC.
I: Street Sweeping & Collection, II: Transport, III: Transfer Station Storage, IV: Final Disposal
Adapted from: *(Ministry of Local Development, 2005; Practical Action Nepal, 2008)*

Public Awareness & Perception

As all of the waste is generated by the people, their involvement is fundamental to establish an effective and sustainable SWM system. A lack of public awareness is one of the key problems of SWM (R. Singh et al., 2015). The SWM Act 2011 (Government of Nepal, 2011) states that solid waste must be separated according to their organic and inorganic composition and so, the differentiation must be understood and made aware to the public. In response to this, KMC has a Community Mobilization Unit (CMU) within the Environment Department created to boost public involvement in waste management and promote 3R principles throughout all levels of society (Water Aid & ENPHO, 2008). The CMU have initiated various programmes to raise awareness of the importance of correct waste management practice including the following (Water Aid & ENPHO, 2008):

- **City Volunteer**: Programme aimed to train young members of society to work as links between the municipality and the community to promote composting and recycling in households
- **Demonstration of Environmental Technologies**: Promotion of adopting household waste management strategies such as composting
- **Community Recycling Centers**: Community recycling centers have been set up to encourage and urge people to recycle their waste
- **Mass Education**: The general public is reached out and informed about proper waste management practices through radio, message boards, and exhibitions

Despite efforts to raise awareness and encourage public participation in the city's waste management through such community-targeted programmes, many residents and even municipal staff are unaware of proper management of solid wastes (Asian Development Bank, 2013b). An example highlighting this is the persistency of scavengers who repeatedly collect waste at the landfill site without any safety equipment and awareness of the health risks they are susceptible to. Also, in some cases, incineration of medical waste is not performed and is mixed along with the municipal waste ultimately ending up at the landfill site, causing serious harm to the surrounding environment and human health (R. Singh et al., 2015).

Although the number of awareness programmes have increased with the steady emergence of green enterprises and active recycling and clean-up activities adopted at schools (Ministry of Urban Development, 2015), widespread waste segregation at the household level or at other sources within the city remains to be seen.

4.2.5. The Aspects of Current SWM Practice in KMC

This section assesses the findings presented in the previous sections based on the elements and aspects of MSWM in KMC, to investigate how it scores on the criteria of sustainability. This involves reviewing the performance of MSW collection and transportation, treatment, disposal, recycling, and reutilization elements through the perspective of institutional, financial, environmental, socio-cultural, and political aspects which are some of the fundamental considerations for the development of an ISWM model, represented in figure 2.

Institutional & Managerial Aspect

The current state of MSWM in KMC is rather ineffective and disorganized due to the alarming rates at which waste is being generated and the municipality's incapacity to cope with it. A lack of a strategic plan providing an overall framework and direction for the management of the MSW generated, and an operational plan outlining activities for the effective attainment of strategic objectives has resulted in the inefficiency of waste management operations (Ministry of Urban Development, 2015). It is evident that there is no clear vision, mission, or goals for the management of the city's solid waste (Ministry of Urban Development, 2015), as the exact reactive nature of management has been ongoing even since the 1990's (Thapa, 1998).

Concerning solid waste generation and collection, the sporadic manner in which the waste is collected is a major issue, resulting in the accumulation of substantial piles of waste throughout the city. The overdependence on a single transfer station and landfill site have not made the waste management scenario any simpler either, with land availability for landfilling activities becoming a growing concern as well. Although there has been the potential landfill site of Banchare Danda identified and acquired, which would mean the diversion of incoming waste streams to the Sisdol facility, the manner of its execution and operation remains to be seen. Also, the municipality has not officially introduced a system allowing and encouraging waste segregation at source (Ministry of Urban Development, 2015). Separation of organic from inorganic waste at source prior to collection would promote a recycling culture and make re-use activities much more effective.

As per the SWM Act 2011, the municipality holds responsibility for the management of solid waste through the construction and operation of specific infrastructure such as transfer stations, processing plants, composting plants, biogas plants, landfill sites, and the collection, transportation, and final disposal of the waste. The lack of efficient manpower, suitable land, access to fitting technology, infrastructure, and sector coordination have restricted the municipality from fulfilling this obligation as there haven't been any processing facilities or bio-gas plants constructed by the KMC as of yet (Ministry of Urban Development, 2015). Along with this, a lack of study and surveys carried out on SWM generation, its composition, and density has compromised the planning of waste collection, storage, transportation, and final disposal.

The transportation system of MSW also faces many inefficiencies. A lot of the operational machinery and vehicles involved in the collection and handling of MSW in the city such as hand-carts, refuse trucks, excavators, and compactors, even currently in use, were foreign aid donations made by countries including Germany, India, and Japan ranging from the years 1988-2005 (Dangi et al., 2015). It was also observed that out of the total number of municipality vehicles recorded in the inventory of the MSWM of the city (see Appendix C), about 54% were not functional, highlighting the misuse of certain heavy machinery that couldn't be utilized effectively as SWM aid. The inclination of the Nepali government to accept any aid that is extended without any consideration of its actual necessity and know-how, has most definitely contributed to the poor maintenance and operation of the received machinery and technology (Dangi et al., 2015).

An important characteristic of solid waste, its density, is an imperative factor to estimate and plan for the volume of required waste containers and vehicles required for its timely collection, transportation, and storage. The KMC has not conducted any study of the density of the MSW generated in the city as of yet, which has also impacted the collection and transportation systems of waste throughout the city (Ministry of Urban Development, 2015). Regular monitoring, surveying, and annual reporting of waste generation, its composition, its density, and performance of collection, transportation, storage, and disposal of waste is also not carried out by the municipality which has led to the continual disorganized SWM system.

Financial Aspect

Financial resources are vital for the development and daily operation of a SWM system. In the case of KMC, the percentage of the budget allocated for SWM is very low. On average, the budget for SWM is 24.86% of the total municipality budget for environmental protection. Table 7 presents the annual allocation of the SWM budget compared to the total municipality budget for environmental protection for the fiscal years running from 2010 until 2017.

Table 7. Amount of Budget Allocated to SWM as Compared to the Annual Environmental Protection Budget in KMC from 2010/11 – 2017/18

Sources: *(Asian Development Bank, 2013b; Ministry of Urban Development, 2015)*

Fiscal Year	Total Municipal Budget (NRs. million)	Budget Allocated to MSWM (NRs. million)	Percentage of Total
2010/11	1,212.85	278.61	22.97
2011/12	947.41	253.13	26.72
2012/13	1,900.00	443.10	23.32
2013/14	2,630.89	621.70	23.63
2017/18	1,513.90	418.70	27.66

An important observation is that the allocated budget has always been underutilized with the majority of the budget expended for the salaries and facilities for the sanitation staff, and fuel and maintenance of vehicles (Ministry of Urban Development, 2015). In comparison, categories such as community mobilization and landfill/transfer station management presented reduced priority, which emphasizes that the municipality has a greater focus on waste collection and transportation (Ministry of Urban Development, 2015).

The municipality collects service charges from service-receivers on the basis of the amount and classification of their solid waste, however, there is much discrepancy concerning this. The municipality provide their waste collection and street cleaning services to 12 out of the 35 wards of KMC (Ministry of Urban Development, 2015). Due to the involvement of private sector waste collectors who charge their own fixed service fees to their clients residing in the remaining 23 wards for essentially the same service, equal service is not experienced by all of the citizens within the city. This, in turn, has resulted in a conflict of interest between the public and private service providers and consequently a highly disjointed sector of service.

Environmental Aspect

The environmental aspects of SWM are somewhat ignored by most of the stakeholders in the city. Unfortunately, the importance of proper environmental practice and its preservation with respect to SWM is secondary to other public services, economic opportunities, and benefits (Asian Development Bank, 2013b), and thus is not regarded as a top priority , even though the situation with waste build-up and the pollution it triggers is amplified with rapid urbanization and population growth.

After having developed an understanding of the current practices of MSWM in KMC discussed in the previous sections, the following environmental impacts resulting from poor SWM can be recognized. The increasing volumes of waste and resulting accumulation of waste on the streets of the city due to the irregularity of waste collection and limited capacities of the transfer station and landfill site have had a detrimental effect on the environment and the population. The overexploitation of the Sisdol landfill site has sparked great concern over land availability for landfilling practices also. The continuous dumping of household waste on streets, unchanging operation of the collection and transportation of MSW, and reiteration of unhygienic waste handling activities, are clear indications that environmental protection and preservation is not given much importance in society. Although there may be households that practice waste segregation and composting at home, the re-merging of waste with the current collection and storage scenario renders the separation at source meaningless.

Social & Cultural Aspect

Customarily, waste work has always been assigned to low-caste[8] members of society and although it has been declared illegal by the government, discrimination still continues in the modern well-educated Nepali society we have today (Gautam, 2011). Due to a common misconception in society, waste handlers and pickers are often viewed as the only members of society that have to deal with waste. As a result, a plethora of the livelihoods of the poor people depend on waste, which is seen as a vital resource (Gautam, 2011).

From their perspective, the endless dangers associated with the unhygienic handling of waste materials can hardly be considered, due to the influence material collection has on their livelihoods (Gautam, 2011). This group in society make up the informal waste worker community and they usually live in slums near dumpsites and are unacknowledged by the municipality and government (Gautam, 2011). They possess valuable knowledge about the quality of wastes throughout the city and possible ways in which the various materials can be saved, transformed, or recycled. As much of the work related to waste is carried out by this group in society, well-off householders are distant from their waste and perceive garbage solely as an annoyance and something that waste pickers and the municipality must deal with. This is the source of the lack of the city's residents' environmental awareness, without any perception that wasteful behavior, modern consumerism and packaging, directly feeds to the issues faced by the MSWM of KMC. The middle-class community in KMC are somewhat aware of the need to protect and preserve the environment, and some also engage in source segregation of waste, which is pointless if the waste is once again mixed by the municipality prior to final disposal. People also sell recyclable waste to nomadic collectors, which can be seen as being driven either by their environmental-friendly mindsets, or the incentive to recoup some of their household expenses by doing so.

Concerning the waste workers, their direct involvement in the waste handling and scavenging of valuable materials from dumping sites makes them most vulnerable to several infectious diseases, such as tuberculosis, hepatitis, asthma, skin infections, etcetera (Gautam, 2011). Without any official support from the municipality waste management authorities, no provision of health services or awareness campaigns, there is no incentive for the waste workers to alter their behavior, thus leading to the continuation of unhygienic and highly risky practices.

[8] The caste system in Nepal, bound by Hinduism, is a complex social system in which a person's status and identity, and roles in society are essentially predetermined. Historically, low-caste members of society or 'Sudras' were forced to be laborers, artisans, and service providers. Although the caste system in Nepal is not as rigid as it once was, it still exists, with people of higher castes and older generations refusing to let go of a system that gives them more dominance over other members of society (The Longest Way Home, 2012).

Political Aspect

As mentioned previously, without a solid strategic or operational plan, a systematic and efficient MSWM system cannot exist. Specific policies, plans, strategies, standards, guidelines, and directives have not been developed by the government and even the municipality responsibilities outlined in the SWM Act 2011 (Government of Nepal, 2011) and SWM Rules (MoEFCC, 2016) documents have not been fully implemented (Ministry of Urban Development, 2015). Some of the problems faced by MSWM in KMC include delayed government decision-making and approval, concerning for example, the procurement of land for potential waste management facility sites from the government, a lack of technical support, and disorganization within the MSW sector. The continuation of inadequate waste management practices and procedures without any visible positive changes, is a clear representation of an ineffective governance system.

Incoordination between the municipality waste management authorities and the non-governmental and private waste management organizations, is another issue that has contributed to chaotic and unsuccessful MSWM operation. The SWM Act 2011 (Government of Nepal, 2011) currently states that only the municipality has the right over the handling of MSW, so involvement from private organizations, even though they are trying to help in the management of increasingly high volumes of waste generated in the city, is regarded as intrusive behavior.

4.3. The Circular Economy Situation with SWM in Kathmandu

The concept of Circular Economy is relatively novel and somewhat unnoticed by many people in KMC. As its principles and advantages are not clearly known or understood, its implementation is not an obvious decision to make. In developing countries like Nepal, and specifically in the case of Kathmandu City, a linear economy driven society exists, in which the take-make-dispose system is dominant. This traditional way of living is regarded as being cheaper and unsophisticated to carry on with day-to-day activities without having to think about the post-use or consumption of products. This careless lifestyle has been embraced by society ever since urbanization of KMC over the last few decades, however now, in conjunction with thoughtless modern-day consumerism, it has severely impacted the capacity of the city to manage uncontrollable levels of waste generated daily. The current scenario of SWM has become more of a ‘sweep and dump’ situation rather than waste management, as summarized by Dipendra Oli, an administrator for the Solid Waste Management Technical Support Centre (SWMTSC) (Azoulay, 2018).

Amidst the chaotic state of the city's waste management system, there has been some glimmer of hope with various young Nepali waste entrepreneurs fighting to battle MSW build-up and the whole perception that the Nepali society has of waste. The concept of 'upcycling[9]' has recently taken off in the city, with the inception of several innovative enterprises aiming for a more sustainable and circular vision for KMC. For example, novel recycling companies, such as *Doko Recyclers* and *Khaalisisi* have started providing free-of-charge waste collection services to households, enabling people to sell their recyclable waste. The types of waste the companies currently accept include paper, plastic, glass, metal, and even 'e-waste[10]', the latter of which the municipality has no systematic way of disposing of currently.

Most of the e-waste ends up in landfills, where it is extremely harmful to the informal workers scavenging for recyclables, as well as to the air, water, and soil (Azoulay, 2018). These companies are currently charging monthly fees to several institutions utilizing their services, to keep their business-model of free service provision for households afloat. Another example of an interesting venture operating in the city is that of *'Tyre Treasures'*, a green enterprise that aims to solve the widespread pollution caused by non-biodegradable inorganic waste in Kathmandu, specifically rubber tyres. Unusable tyres have been upcycled into innovative polished products including tables, stools, furniture, mini gardens, etc.

As stated by the Ellen MacArthur Foundation, "the scale of re-utilization activities in the SWM sector is directly related to extent of CE implementation" (Ellen MacArthur Foundation, 2013). In the case of KMC however, almost all of the actors that have adopted the ideology and practice of re-utilization and regeneration of MSW are private enterprises, NGOs, and informal waste collectors and recyclers. Without a systematic and formal union or forum to allow regular communication and coordination between them, the mentioned stakeholders rarely meet with each other and operate individually. Providing this much needed link between MSW sector stakeholders and bridging waste generation and utilization activities is a key enabling factor of CE (Witjes & Lozano, 2016).

[9] 'Upcycling' refers to the creation or modification of a product derived from waste or used materials, components, and products, which is of equal or higher quality or value than the original (Sung, 2015). It differs from recycling in the sense that the quality and composition of materials for its next use is not compromised.

[10] 'E-waste' is a combination of used, unwanted, or obsolete electronic products that have exceeded their shelf life. Examples include computer equipment, cell phones, batteries, etc. that contain harmful toxic and hazardous substances that require special disposal or recycling treatment (Vats & Singh, 2014).

4.4. The Challenges of Circular SWM Integration

This section discusses the existing barriers that restrict or complicate any possibility of an integration of CE principles in the MSWM of KMC. The obstacles identified will be based on the angles of economy, technology, infrastructure, governance, and society.

4.4.1. Economic Challenges

Financial resources are essential for any activity in society to thrive, and this holds true for the case of MSWM. Unfortunately, the current state of KMC's SWM system is a clear reflection of the lack of resources dedicated to environmental protection and MSWM more specifically. As mentioned in section 4.3.5, the budget allocated for MSWM is insufficient to handle the alarmingly rising levels of waste. The lack of financial support and urgency to repair the current operation of SWM in KMC resonates inadequacy throughout the sector and this has always been the case in the city. The recurrent under-utilization of the allocated budget in recent years (Ministry of Urban Development, 2015) has also indicated that MSWM is not given priority over other public services.

The scale of economy of SWM related enterprises such as the aforementioned recycling and upcycling initiatives is quite low, as most of these innovative businesses are primarily young start-up companies with limited recruitment. There doesn't exist any subsidy scheme or incentive currently, to encourage and promote waste management initiatives, which has in turn also restricted the formal sector's involvement in waste re-utilization and regenerative practices.

4.4.2. Infrastructural & Technological Challenges

Development of infrastructure has always been a major concern in Nepal, stemming from both complications in its topography, being landlocked and having areas with very limited accessibility, and also the limited finance available for the country's development. This is undoubtedly apparent in the MSW management and sector operation in Kathmandu.

As highlighted in the previous section, there are numerous inefficiencies in the collection, transportation, and final disposal or treatment of MSW. For instance, more than half of the municipality vehicles and machinery for collection and transfer of waste are not functioning, as they were mainly foreign aid donations from the late 1980s and 1990s. Many of the vehicles in operation have limited storage capacities and face difficulties transferring the generally substantial volumes of MSW amassed on the streets, leading to inefficient collection and transfer. The municipality, therefore feels that there is an insufficiency of vehicles dedicated to waste collection. On the contrary however, it was found that several hermetic self-discharging garbage trucks received by the municipality in 2010, sat unused and inactive at the Environmental Department in Teku (Ministry of Urban Development, 2015). Also, it was found that municipality trucks had been collecting waste from depots in areas which were the private sector's responsibility and charging service fees from households for providing the collection service (Ministry of Urban Development, 2015).

The absence of waste separation by the municipality is another limitation of the current MSWM set up. There is currently no assurance that source-segregated waste is to stay separated throughout the waste supply chain, and so, is often mixed after municipality collection, ending up being dumped in the same landfill site. Although the provision of segregating organic from inorganic waste and separate segregation containers for neighborhoods by the municipality is mentioned in sections 6 and 8 the SWM Act 2011 respectively, the municipality have not provided separate containers to the people for waste segregation at source (Ministry of Urban Development, 2015).

A shortage of waste management facilities such as waste sorting centers, transfer stations, and landfill sites, with the persistent overexploitation of the Teku transfer station and Sisdol landfill site, has indeed held back the development of the SWM system in the city, with significant build-up of hazardous MSW, causing irreversible damage to the environment and public health of its inhabitants. Although land has been secured and agreed upon for an alternate landfilling sites to deviate waste streams away from Sisdol, which has been an issue for the municipality for several years, it is not a long-term solution to the inadequacies in the MSWM of KMC.

The incompetency of municipality workers within the SWM sector of KMC is also an issue that could complicate the shift to a more sustainable waste management system (Ministry of Urban Development, 2015). The municipality has admitted that the human resources are inadequate for the management of the city's solid waste (Ministry of Urban Development, 2015). The inadequacy of the existing manpower has directly affected the overall efficiency in SWM activities from collection to disposal services.

In conclusion, unless SWM budget resources are utilized and applied correctly, prioritizing the regular training of personnel, and the procurement, management, operation, and maintenance of suitable SWM facilities and equipment, there is no guarantee that the current disorganized situation will not repeat itself.

4.4.3. Governance & Sectoral Challenges

The managerial aspects of MSW generation, collection and transportation, storage, and disposal are not as refined as one would prefer them to be in the case of KMC. Without a strategic plan or long-term vision for managing solid waste in a systematic and integrated manner, the city and its inhabitants have long been exposed to damaging effects from a flawed MSWM. The municipality, which holds sole responsibility of SWM activities in KMC, have not established any specific policies or directives to guide suitable waste management practices. The highly irregular and uncoordinated manner at which waste collection is performed is a direct reflection of the detached relationship between the public and private waste collection sectors. With minimal regulation and communication between the two sectors, it is difficult to ensure firstly, the consistency of waste collection services, and also the efficient and environmentally-friendly waste handling operation by the private sector.

As mentioned earlier, the private MSW related businesses are operating in a very detached manner, as there is no formal union or platform to connect them with each other and with the public and informal waste management actors. This lack of coordination between the stakeholders will most definitely be an obstacle that will need to be overcome if there is ever to be an integrated and circular MSWM system for the city.

The Environment Audit Report of the SWM of KMC carried out in 2015 (Ministry of Urban Development, 2015) also indicated a lack of database within the municipality concerning the statuses of operating waste management entities within the city, and a complete absence of impact monitoring and compliance monitoring according to both Environmental Impact Assessment (EIA) recommendations and national environmental standards. Also, without any study, survey, and reporting of important waste generation components such as the generation rate, density, and composition, the planning and efficiency of waste collection, transportation, storage, and its disposal has been heavily compromised. This critical shortcoming in sector revision, monitoring, and reporting suggests that the involved municipality authorities are not fully committed to rectifying the current environmentally-negligent scenario, which has resulted in the worsening of the overall MSWM situation.

4.4.4. Societal Challenges

For a city's MSWM system to flourish, the full commitment and cooperation of its inhabitants is essential, since it is essentially people who generate the waste. In the case of KMC, several societal barriers exist with regards to waste, its handling, and management. The current public perception of waste shared by the majority of the city's inhabitants, is sure to be one of the primary obstacles that would restrict the implementation of CE in the MSWM of KMC. As a large portion of the population see waste merely as a nuisance that should be dealt with solely by the municipality and waste workers, its damaging impact on public health and the environment and also its role as a potentially valuable resource, is only fully understood by the people who are constantly in direct contact with it. Such people are mainly the informal waste collectors and scavengers, whose livelihoods depend on solid waste collection. Sadly, these communities are still looked down upon by society even to this day, despite the fact that they are the 'living machines' helping to keep KMC clean (Gautam, 2011). Unless this common view of waste workers is altered, and the work they do is recognized as being for the benefit of the city's environment and people, waste will forever be perceived as merely something we dispose of and nothing else.

The lack of public awareness of and participation in environmentally-friendly waste management practices is another issue that could hinder the shift towards a more sustainable MSWM system. Although there have been several awareness programmes both from the municipality and non-governmental bodies, the continual reckless behavior of the public concerning illegal dumping and open burning of their waste is an indication that they are not being successfully reached and informed.

As CE adoption requires a complete customary and habitual change from society, in the case of MSWM, it is essential for people to build sustaining habits for waste reduction, recycling, and re-utilization. In the case of KMC, as the sorting waste and recycling habits of its citizens are still relatively low, it will certainly be an obstacle to overcome that will require the active involvement of all members of society to help induce a lifestyle based on the 3R principles of waste, which was modelled by C40 Cities Climate Leadership Group (2015) and introduced by Lansink (1979) in the "Waste Hierarchy" framework.

4.5. CE Integration into Waste Management Sectors of Other Countries

This section discusses two instances of CE integration into SWM systems that are relevant for the possible shift towards a more sustainable MSWM structure in KMC. The two cases considered are the implementation of organic WtE systems in *India,* which mainly concerns technological capacity, and the circular zero-waste transitioning of communities in *Japan and South Africa,* which concern social behavioral changes and public perception of waste. The mentioned cases are examined and discussed to highlight any enabling factors that could possibly ease the transition into a more circular waste management system.

Organic WtE Systems in India

Similar to Nepal, organic MSW makes up the bulk of waste generation in India (Dhar, Kumar, & Kumar, 2017). With the realization of this, the Government of India had responded by establishing 1 million small-scale and over hundreds of community anaerobic digestion (AD) plants throughout the country (Annepu, 2012). Up to four million biogas plants have since been installed in the country (Abbasi, Tauseef, & Abbasi, 2012), with biogas technology incorporated by the government as one of the major WtE options to be developed and utilized in the country (Government of India - The Ministry of New and Renewable Energy, 2018). As rapid urbanization and consequent population growth continues to be an unmanageable issue in the country, the management of increasing levels of MSW has become one of the chief priorities. The organic waste stream in India is identical to Nepal, consisting of the organic content of MSW, agricultural waste, waste water, and animal dung (Dhar et al., 2017). Also similarly to the MSWM system of KMC, the majority of MSW is openly dumped, with only 21.45% of it treated and a substantial amount disposed of on landfill sites (K. J. Singh & Sooch, 2004).

To tackle both issues of critical levels of MSW generation and public energy demand, WtE technologies have been deployed and adopted throughout the country. WtE in India is mainly categorized into two processes, consisting of thermo-chemical and biological technologies. Thermochemical WtE technologies in India include gasification, incineration, and pyrolysis, involving the appliance of heat or temperature and chemical reactions to generate energy from biomass or organic waste, and are best suited for organic waste holding high calorific values and low moisture content (Dhar et al., 2017).

Examples of biological WtE technologies that are in operation in India include anaerobic digestion (AD) and fermentation, which involve the natural breakdown of biomass into liquid fuels by microorganisms and bacteria. Biological WtE technologies like AD are recommended for high moisture content organic wastes (McKendry, 2002).

AD has emerged as a commercially proven WtE technology in India and is regarded as the solution to divert organic waste streams away from landfill sites and prevent any environmental damage from the uncontrollable breakdown of organic matter dumped in these sites (Ambulkar & Shekdar, 2004). As the organic composition of MSW is never of consistent and depends on several factors such as climate, the extent of recycling, regularity of collection, cultural habits, and seasonal changes, the efficiency and success of AD technologies can be varied. The digestion processes can consequently be enhanced by source separation of organics in MSW, potentially yielding biogas with a calorific value of 21.6 MJ/m^3, allowing it to be utilized for transportation purposes (Uusitalo, Soukka, Horttanainen, Niskanen, & Havukainen, 2013).

More recently, a motivating initiative under the central subsidies plan of the Ministry of New and Renewable Energy has taken off, seeing the launch of biogas-powered buses in the city of Kolkata. 'Phoenix India Research and Development Group', a Kolkata-based company had designed a 54-seater bus that runs on biogas produced from human and animal waste over a 17.5km route in March 2017 (Feature, 2017). The public fare for the bus is said to be Re.1 (€0.01) regardless of distance travelled along its designated route, successfully establishing it as the cheapest mode of public transport in the country (Bhattacharya, 2017). Similarly, the Goa Government has also introduced ethanol-powered buses, running on biogas generated from MSW at the SWM plant in Saligao (The Times of India, 2017). Both of these green initiatives are circular pilot projects in a movement to reduce dependency of landfills and change the public perception of waste, showcasing its potential value in society.

As a large portion of the MSW generated in KMC is organic, and diversion of waste streams from the Sisdol landfill has become a necessity, AD of the city's MSW, learning from the success of green initiative implementation in the neighboring country of India, could be a sustainable option for the city to consider.

Zero-Waste Initiatives in Practice

Public perception and behavior towards sustainable waste management is a crucial component that directly influences a city's MSWM. In the case of KMC, the lack of awareness and negligence of the public towards waste and its prevention and reduction has long since proven to be a catalyst for the failure of the city's solid waste management.

In the past, similar problems with KMC's MSWM like the ones discussed in the previous sections were also experienced in Japan between 1950 and 1970 (R. Singh et al., 2015). The waste system has gone through significant transformation and the city of *Tsukuba* and the town of *Kamikatsu*, are prime examples of government action and public solidarity playing influential roles in the shift towards circular SWM systems. With urbanization and industrialization in the 1980s (R. Singh et al., 2015), the lifestyles of the Japanese people changed, inducing the increase and nature of wastes, which can also be noticed in the extent of plastic waste generation in KMC. To combat this, the Japanese government formed progressive policies based on the 3R principles of waste to promote recycling between the 1980s and 1990s.

A material-cycle society has since been established, forming an integrated waste management system throughout the city of Tsukuba. MSW in the city is segregated into several categories such as combustible waste, aluminium cans, glass bottles, incombustible waste, paper, cloth, and oversized garbage, with special waste such as dry-cell batteries and fluorescent tubes required to be taken to repositories or designated community centers for disposal (City of Tsukuba, 2018). Every single resident of the city is given a calendar with information concerning waste, the collection schedule, and instructions for source segregation, thus keeping the public well informed about the importance of waste management and promoting a sustainable lifestyle throughout society. All of the recyclable materials serve distinct purposes, with recycled pet bottles reused to make textiles, egg containers, or stationary; aluminium cans reused in the automobile industry; and magazines used to make high-quality paper products. Municipal tax collected from the city's residents, of which is primarily used for the management and re-utilization processes of the MSW, and the cooperation from the public has completely revamped a once inefficient and disjointed waste management sector to a highly proactive and effectual one.

The small town of Kamikatsu, is now notorious worldwide for its quick transformation into a 'zero-waste' community. Like Kathmandu, it also had an inadequate MSWM system with its inhabitants openly burning all types of waste and performing illegal dumping of their waste into open spaces, much like the scenario in some areas within KMC (Milian & Watanabe, 2009). On the 19th of September 2003, Kamikatsu made a Zero Waste declaration outlining its intention to build an environmentally sustainable society and completely eliminate the amount of waste sent to incinerators or landfills by 2020.

Currently, 80% of the town's solid waste is either recycled, reused, or composted, with only 20% going to a landfill site (Garfield, 2017), compared to a 51% recycling rate in 1999 (Milian & Watanabe, 2009). This is down to the aggressive waste segregation system employed by the residents and the full commitment and enthusiasm of its people to work towards the zero-waste declaration objectives. The unique waste segregation system consists of a classification of 34 types of wastes and requires people to bring their waste to a central waste station, as there is no municipal waste collection service to gather waste from households or street containers (Milian & Watanabe, 2009). Figure 20 shows the unique waste segregation system employed in Kamikatsu.

Fig.20 Waste Segregation in Kamikatsu
Source: *(Gigazine, 2018)*

The most fascinating element of this MSWM system is that participation in the initiative is completely voluntary, without any formal fiscal or economic mechanisms or incentives forcing the residents to partake (Milian & Watanabe, 2009). Community composting is also encouraged, with provision of a subsidy to cover up to 50% of the cost of electric composters for either households or businesses. To prolong and preserve the art of circular zero-waste living, local schools have incorporated education on waste, recycling, and the environment to raise public awareness at an early age. This is a total contrast to the awareness scenario of KMC, where even some of the SWM sector personnel lack awareness about environmentally friendly waste management. Kamikatsu has also organized a waste exchange center known as the 'Kurukuru', to which the locals can bring in any unwanted items such as clothing or furniture, and freely exchange their old belongings for items that others have left (Milian & Watanabe, 2009). There is also a unique factory where local women fabricate new items like hand bags and pillows from old discarded clothes (Garfield, 2017). Although, there exists similar waste innovation initiatives in KMC like 'Tyre Treasures' discussed in section 4.3, it is limited to a single type of waste material, and public awareness and acceptance regarding such green enterprises in general, is relatively low in the city.

One other interesting step towards a circular waste management system has been taken in the city of Cape Town in South Africa, where a free online system known as the 'Integrated Waste Exchange' or "IWEX", has successfully connected individuals, businesses, and schools that want to exchange any of their unwanted materials or waste. This waste exchange platform, similar to the 'Kurukuru' in Kamikatsu, is operated at a much larger scale, embracing communication technology as the medium to allow for efficient exchange of material, thus minimizing solid waste disposal to already exhausted landfills and the build-up of new landfills (Altamirano, Maassen and Prieto, 2017). The key intention of the platform is to link waste material generators to waste material users, through the creation of a circular flow of materials such as textiles, batteries, metals, etc. which has saved users a large amount of money and energy, whilst deviating MSW away from landfill sites.

4.6. Energy Generation Potential of Municipal Solid Waste in Kathmandu

Despite the noticeable link between MSW and energy, the concept of Waste-to-Energy (WtE) is still relatively unexplored in the country and is viewed as a lesser means of energy generation in comparison to the widely adopted and developed hydropower technology, as highlighted in Chapter 2. Although waste prevention, reduction, recycling, and reusing are the most preferred approaches for MSWM, depicted by the waste hierarchy (see figure 1), the utilization of MSW as an energy resource can play a key role in SWM (M. E. I. Shrestha, Sartohadi, Ridwan, & Hizbaron, 2014). It is, however, difficult to determine suitable Waste-to-Energy (WtE) technologies without first verifying the quantity and composition of generated waste (Idris, Inanc, & Hassan, 2004).

In the case of KMC, as both MSWM and energy security are becoming growing concerns, the successful implementation of WtE could play a vital role and contribute in the rectification of both flawed sectors. Before investigating the various thermal and biological WtE technologies, it is essential to determine the energy content or potential of KMC's MSW. Given the heterogeneous nature of MSW composition and the varying calorific values the different waste components possess, establishing a uniform energy potential for the MSW is not yet possible. However, the theoretical energy content of the specific MSW composition established by ADB's study on KMC's MSW generation and composition (see table 4) can be estimated using the following formula (Zaman, 2010) and heat values of the solid waste components shown alongside their fractional contents in table 8:

$$\boldsymbol{E} = \sum \boldsymbol{f_i} \times \boldsymbol{HV_i}$$

Where,

$\boldsymbol{E} = Theoretical\ Heat\ Content\ (million\ Btu/ton)$
$\boldsymbol{f_i} = Fraction\ of\ waste\ component\ i\ in\ total\ MSW\ composition$
$\boldsymbol{HV_i} = Heat\ Value\ of\ waste\ component\ i\ (million\ Btu/ton)$
$1\ million\ Btu/ton\ =\ 2.93071 \times 10^{-7} MWh$

Table 8. Heat Values of Solid Waste Components on Dry Basis and Fractional Contents of Each of the Waste Components of KMC's MSW
Source: *(United States Environmental Protection Agency, 2018a)*

Component	Heat Value (Million Btu/ton)	Fractional Content in KMC's MSW
Organic Waste	7.6	0.43
Plastic	22.6	0.22
Rubber & Leather	20.65	0.01
Textiles	13.8	0.03
Glass	0.1	0.03
Paper	6.7	0.25
Metal	0.7	0.02

Using the aforementioned formula, it is calculated that each tonne of MSW in KMC has the potential to produce *10.43 million Btu*, meaning that a total of *3.06 MWh* of energy can theoretically be generated from MSW in KMC each day. Even if only the organic waste content is expended, with other components either recycled or reused, *3.29 million Btu* (*0.96 MWh*) can essentially be produced daily.

Other than the theoretical energy potential of the MSW composition, the moisture content of waste is a critical factor that must be considered when calculating the energy content of waste material and proposing a suitable WtE technology (Sodari & Nakarmi, 2018). Study conducted by Sodari and Nakarmi verified high moisture content in the city's organic waste (70%), with paper waste containing 20%, and plastics comprising of 5% moisture. From table 8, it can also be seen that plastics contain the highest energy content, with organic and paper wastes sharing similar energy potential. As the portion of organic waste is normally higher than that of plastic waste in KMC's total MSW composition, it will ultimately have a higher contribution in the overall energy content of the city's MSW in the long run.

Suitable WtE selection is dependent on a wide range of variables including economical, technical, and societal feasibility and it is impossible to recommend one universal solution for all scenarios. Contextual knowledge is crucial to consider and so, given the high content of organic waste in the MSW of KMC and the new sanitary landfill site in Banchare Danda planned, an AD plant could be established and incorporated on-site. This would not only divert MSW away from accumulating on the landfill sites, but also offer a high degree of renewable energy recovery from the waste, due to the biogas conversion from the organic fraction of municipal solid waste (OFMSW).

As long as source segregation and the separation of organic waste material is monitored and regulated, AD incorporation at the landfill site can be a promising option to reduce landfilling practices and give a second-life to materials that would otherwise be considered as waste and discarded (Ellen MacArthur Foundation, 2015). Prolonged accumulation of organic waste in landfills release methane and carbon dioxide into the air which directly contributes to climate change. AD addresses this concern by diverting organic waste content from landfills, thus reducing GHG emissions. AD processes also produce digestate, a slurry rich in nutrients, that can be utilized as an organic fertilizer or soil enhancer to maintain soil for agriculture (United States Environmental Protection Agency, 2018b).

5. Conclusion

In this section, the questions intended to be answered by the undertaking of this research are addressed. Current practices of MSWM in KMC and their consequential environmental impacts are reviewed. A feasible circular SWM framework is discussed, taking inspiration from the success of other cities which have integrated CE into their MSWM, whilst highlighting various challenges for the SWM setup of KMC were it to one day make its transition towards circular MSWM. After having investigated the current practices and circumstances concerning municipal solid waste and its management in Kathmandu Metropolitan City, it was understood that a very fragmented MSWM system is currently in operation, with an urgent need for amendment.

Current and incessant damaging practices across various levels of society have been catalysts for the incapacity of the MSWM sector to handle the critically rising levels of waste. Large piles of mixed MSW are accumulated roadside and in open public areas due to a highly irregular waste collection system, illegal dumping, and an absence of the source segregation of waste. A disjointed public-private waste collection system has contributed to this inconsistency. All of KMC's collected solid waste is ultimately taken to a single landfill site which has been overexploited and merely serves as a dumping site currently as a result.

The continuation of such practices in the city has had a destructive impact on the environment and the wellbeing of its citizens. The illegal dumping and resulting accumulation of mixed waste has adverse effects on public health, intensified by occurrences of hazardous medical waste contamination at dumpsites and the Sisdol landfill. The landfill, which was intended to be a sanitary semi-aerobic system that manages hazardous leachate buildup and spread, has not performed to standard. A lack of regular examination and maintenance of the site and the drainage system has led to the accumulation and leakage of acidic leachate contaminating the soil and groundwater. An absence of appropriate health and safety workwear and equipment on site also puts the waste workers in major risk of respiratory and skin problems, with continuation of unsanitary waste handling and scavenging.

Various concepts of circularity have been introduced in countries like India, Japan, and South Africa which can serve as a motivation for KMC to follow suit. As discussed in Section 4.5, the regions of Tsukuba and Kamikatsu in Japan have swiftly adopted a zero-waste mentality sparked by proactive government action and full commitment and cooperation from the public. In the case of Kamikatsu, aggressive segregation from source, initiated wholly by the town's inhabitants has, over time, changed public perception and behavior concerning waste, which is a key enabler for the integration of circularity in SWM.

To further ensure sustainability and the continuation of circular SWM practices, the inclusion of environmental protection and proper waste management in the educational system of Kamikatsu is implemented to promote environmentally-friendly behavior amongst its youngest members of society. Daring and unwavering government action to promote, urge, and embrace the nationwide generation and utilization of biogas in India is an indication that authority can play a vital role in guiding cities towards a more circular SWM system. Also, the IWEX programme in South Africa linking all of society in a trade of waste materials through on online platform, is a prime example emphasizing the importance of technology and the significant influence it can potentially have in CE integration for a city's SWM. These are all cases from which KMC can learn from and build upon for the development of its own circular MSWM set up.

For a circular MSWM to develop in KMC, a framework requiring the active participation and cooperation between all stakeholders is crucial. Waste must be required to be segregated at source with the provision of specific waste containers or bins by the municipality. Open dumping of mixed waste must be eliminated, with designated collection locations established for neighborhoods to place their containers at, given the clustered nature of households within the city. Formal waste segregation will encourage more efficient waste collection from the public and private collectors, who must operate in unison and adopt a more coordinated approach than the presently existing scenario. Waste collection routes and schedules must be planned for regular collection from both sectors with thorough monitoring of segregation, ensuring that MSW stays separated throughout the waste supply chain after collection. With land for a new proposed sanitary landfill site secured, a WtE AD plant along with resource recovery and recycling facilities could be constructed for increased efficiency of the transfer of waste materials for energy generation, recycling, or re-utilization. As the informal sector have been and are most involved in recycling activities within KMC, they could be formally integrated into the operation of the recycling and resource-recovery centers. By doing so, the recyclable or re-utilizable waste material can be distributed or circulated to the recycling industry within the country or to any emerging green enterprises involved in upcycling activities for instance, thereby eliminating the need to export any potentially valuable materials.

A transformation of the current disorganized waste supply chain of KMC into a systematic waste value chain is urgently required, however, various challenges complicate the matter. Economically, an insufficiency in the budget dedicated to environmental protection and MSWM is a major issue faced by the sector. As a result, the scale of economy of SWM related enterprises is low, with no formal subsidy scheme or incentive for the encouragement or promotion of waste management initiatives provided by the government.

Concerning the present infrastructure with MSWM, inefficiencies in collection, transportation, final disposal, treatment of MSW, together with an insufficiency and incapacity of technical human resources to operate machinery will complicate CE integration into the sector. A shortage of SWM facilities such as sorting centers, transfer facilities, and landfill sites is another obstacle that will be required to overcome if the sector wishes to be more sustainable and effective.

An absence of a long-term strategic plan for SWM in an integrated and methodical manner and established policies or directives from the government to guide appropriate waste management practices, is another concern that could hinder the potential integration of CE into the sector. A lack of coordination and communication between the public and non-governmental sectors also needs to be addressed with each sector operating independently currently. A lack of data management and monitoring by the municipality authorities with minimal follow-up of SWM related issues or concerns raised will need to be rectified, with regular reporting of studies and surveys conducted on critical factors such as the MSW generation rate, density, and composition characteristics, all of which will improve overall efficiency of MSWM procedures.

Overcoming challenges concerning the societal aspects of MSWM is equally vital as it is complex. The public perception of waste will need to change from recognizing waste as more than just a daily nuisance that should be handled by the municipality to something that is a shared responsibility of all members of society. The inhabitants of KMC must realize the irreversible effects caused by uncontrollable build-up of MSW due to poor management and also, its potential to serve as a valuable resource that can be re-utilized. Environmental awareness can only be achieved if there is full cooperation and commitment from society and therefore, adoption of environmentally-friendly waste management practices, segregating and recycling habits, and ending illegal dumping and unsanitary waste handling must be incited by the public for a more integrated and circular MSWM sector.

In conclusion, the integration of CE principles into the MSWM strategy of KMC, given the current circumstances, will require a collaborative approach, with full dedication and cooperation between all stakeholders in society, most importantly the public, as they are the primary contributors of the city's waste. Formal source segregation and home composting are the initial steps that can stimulate potential integration of circularity, as they will create a cumulative effect translating into systematic waste collection and transportation, and ultimately recycling or re-utilization. Public-Private collaboration requires strengthening with the implementation of a formal system, highlighting specific roles and responsibilities of each of the concerned bodies, as the private sector involved in MSWM possesses indispensable technological knowledge and capacity that would benefit the entire MSWM setup of KMC were it to be formally supported by the government. Only then, can a sustainable and circular waste management system take fruition within the city.

6. Recommendations

This section discusses what is required from the primary stakeholders involved in the MSWM of KMC. After investigating and highlighting the current inefficiencies across the waste management sector in the previous sections, actions or measures concerning the municipality, private and non-governmental bodies involved in waste management activities, and the inhabitants of KMC to allow for a more circular MSWM system will be outlined.

Visualization of a Suitable Circular MSWM Framework for Kathmandu

Figure 21, developed by the researcher, portrays a reimagining of KMC's MSWM system with the adoption of CE principles, resulting in a more sustainable waste management system. It begins with waste being segregated at source, which is an essential component to help reduce waste, a top-most priority highlighted in the waste hierarchy (see figure 1). Municipal and non-governmental (private waste management companies, NGOs, itinerant waste collectors) waste collectors will be required to coordinate and work concurrently, collection waste from designated collection points established at various neighborhood locations. The segregation of waste must be ensured and not be interfered with by the waste collection personnel after collection, with organic waste being transported to a WtE AD plant, and recyclable or re-utilizable waste being transferred to a resource recovery or recycling facility. The organic fraction of municipal solid waste (OFMSW) can be utilized to generate energy in the form of biogas, which can consecutively be used to fuel vehicles or serve as cooking fuel for instance. The recyclable or re-utilizable content of MSW comprising of paper, plastic, metals, glass, and textiles can be distributed or circulated to the recycling industry or green enterprises such as upcycling initiatives to keep material resources circling in loops, moving from a waste supply chain towards a value chain of products and services, which is a core enabling dynamic of a circular economy (De Angelis, Howard, & Miemczyk, 2018).

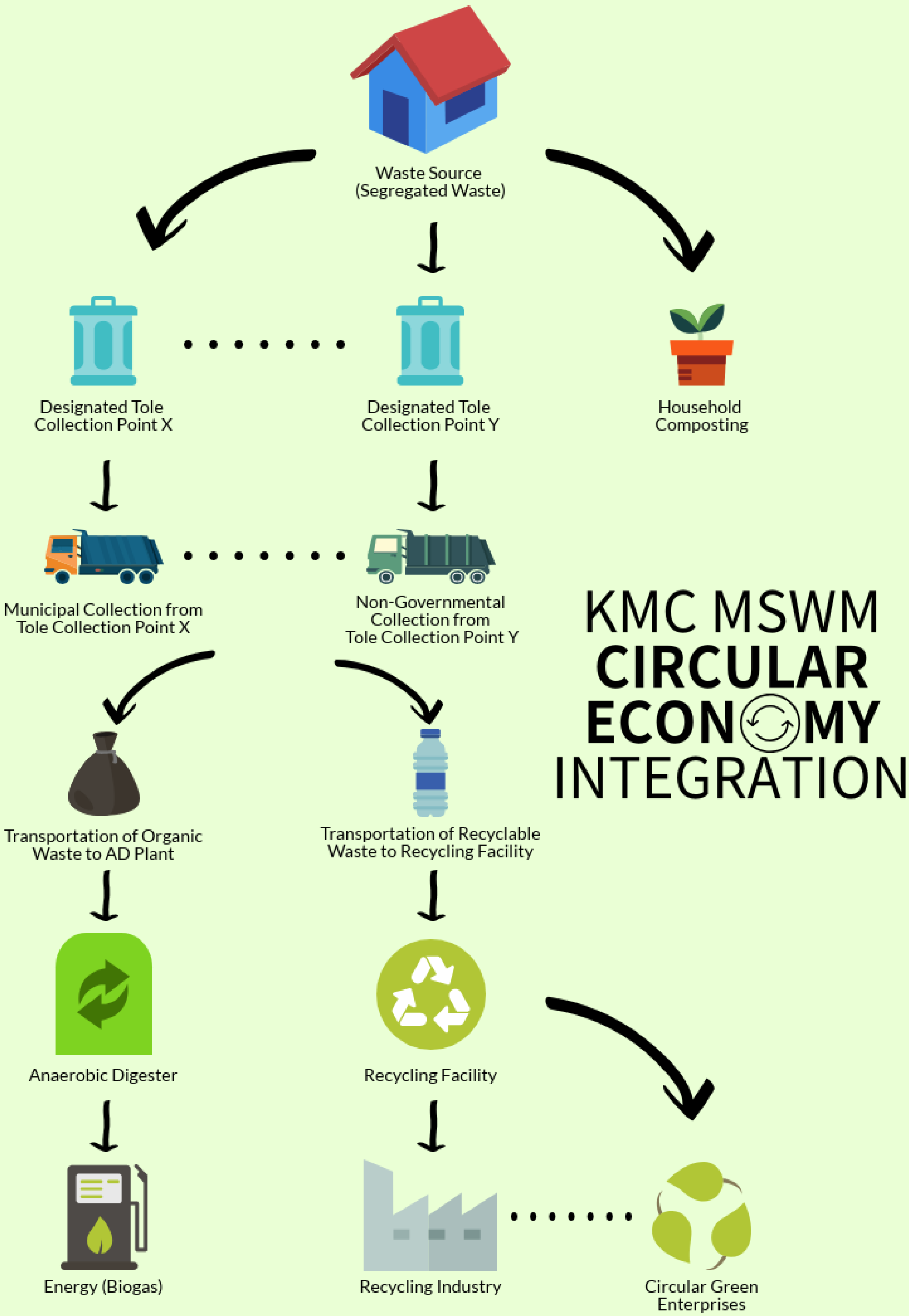


Fig.21 A Re-imagination of KMC's MSWM System with the Integration of Circular Economy

The Suitable Circular MSWM Framework for Kathmandu

While the SWM Act 2011 was indeed a progressive step towards correcting MSWM practices nationwide, it clearly has not been successfully translated into action. Based on the unmethodical operation of SWM in the city discussed in the previous sections, the municipality, who holds maximum responsibility, has to take significant steps in revamping the current scenario of KMC's MSWM.

Clear strategic direction is essential, with an urgent need for an updated policy and strategy, detailing key objectives, guiding directives, and an implementation plan with a tangible timeline and well-defined performance monitoring and assessment protocol. Regular tracking and update of waste management activities, performance, and data should be executed to improve efficiency of waste collection, its transportation, and treatment, whilst also enhancing the capacity of available human resources.

Although, contrary to the SWM Act 2011, formal incorporation of private and non-governmental waste management organizations in the MSWM system of the city is a necessity, as this cooperative approach can promote a more coordinated system of waste collection, transportation, and treatment procedures like recycling. Although a recent partnership has been forged with the private waste management joint venture Nepwaste, a full integration of private companies such as 'Doko Recyclers' and 'Khaalisisi', involved in waste management activities throughout the city can alleviate burden on the municipality to deliver MSWM services independently. Also, the informal waste sector consisting of the wandering waste collectors and scavengers, can for example, be formally recognized and incorporated into an official recycling and reutilization division within the MSWM set up, with regular performance monitoring and review. The formation of an official recycling and reutilization sector adopting strict health and safety measures for waste handling would be beneficial for both the waste workers and the city's unsegregated MSW build-up problem.

Resource recovery or recycling facilities may also be constructed near final disposal sites to allow efficient transfer of recyclable or reusable waste material. This would also ensure that waste materials are recycled and reutilized within the country, reducing the need to export recyclables to neighboring countries. This will in turn, provide a completely new economic opportunity in society, offering chances for novel green enterprises such as upcycling initiatives to flourish.

Current environmentally harmful practices must be eliminated firstly. The collection of MSW from open exposed piles on the roadside for example, is extremely unhygienic, posing multiple health risks and damage to the environment. As discussed in section 4.2, the unmanageable build-up of waste in these open spaces throughout the city has made regular municipal waste collection very difficult.

In response to this, several private waste management initiatives have emerged to help the city address this issue. However, the incoherent nature of and disparity in public and private waste collection services mentioned in section 4.3, is a clear indication that a platform or forum is required to link the private waste management with each other and with the municipality, thus improving coordination between all relevant stakeholders.

The municipality waste management authorities also have great responsibility in the promotion and implementation of public practice of 3R and waste segregation. 3R has the capacity to substantially reduce the amount of waste disposed at the Sisdol landfill site, thus saving costs for unsanitary final disposal, and lowering consequential risks to public health and the environment. Waste segregation is a concept that needs to be exercised by all members of society throughout the waste supply chain. Separation of waste types into at least organic and inorganic waste for example, will not only considerably improve the efficiency of waste collection and its transportation, but can also unlock the possibilities of waste re-utilization, whether it be through recycling or WtE procedures.

The municipality must promote and urge source segregation with the provision of independent waste containers or bins for different types of waste. Public awareness and perception of waste and its proper management should also be addressed to firstly eliminate littering in public places, promote waste segregation and composting of organic waste, and increase community involvement and cooperation in the management of the city's solid waste. Informative campaigns to enhance public awareness of 3R and proper SWM will have to be stimulated by both public and non-governmental bodies involved in waste management activities. Environmental protection may also be incorporated into educational systems to raise awareness and promote environmentally-friendly practices amongst the young members of KMC's population.

The abolition of environmentally destructive public behavior leading to substantial waste build-up in the city such as reckless consumption, illegal dumping of waste, negligence, and ignorance towards environmental protection is crucial for the transition towards a more effective MSWM system. Public cooperation and commitment to adhere to a systematic and regular segregated waste collection system, should there be one enforced by the municipality, will be compulsory to ensure sustainability and continual success of the sector. A strict *'Polluter Pays'* system must be enforced to prevent the continual dumping of waste and stimulate environmental consciousness, in which people are held responsible for the damage done to the natural environment by paying penalties or fines. There should also be a willingness from the public to accept and pay a suitable service charge in exchange for effective and consistent management of the city's MSW with realization that a circular and sustainable MSWM system is beneficial for society as a whole, as it aims to eradicate any potential risks to public health and the environment from exposure to incessant MSW build-up, thus improving living conditions for all inhabitant of KMC.

As a recommendation guide for practitioners, successful CE integration firstly involves collaboration outside the various stakeholders' comfort zones. Due to the integrated nature of CE, implementation of its principles in a social system requires business models to value and involve stakeholders from a variety of sectors. Integration of CE must be executed at the appropriate scale and only then should it be gradually expanded. Effective integration at the metropolitan scale is only achievable through successful integration at the household scale, for instance.

Priority of critical sectors such as waste management must be acknowledged and given by governing authorities, enabling a foundation to initiate CE implementation. Lastly, for developing cities such as KMC, CE should be recognized as an advantageous development opportunity, requiring full commitment and support from the government to facilitate its incorporation through the securing of pilot project funding to realize its capability and importance in society. Only after this network of collaboration and financial support is achieved, can a circular SWM system be applied and progressively scaled up as required.

Recommendations for Further Research

Although this study emphasizes the importance of integrating the concept of Circular Economy into the solid waste management setup of KMC, there is both scope and requirement for further exploration and research to potentially shape a more circular and sustainable future for the waste management system. The economic, technical, social, and environmental feasibilities of the proposed MSWM framework must all be assessed, for instance, to gain a thorough understanding of all the possible benefits of transitioning into such an arrangement. These could include the enhancement of environmental protection, the emergence of job opportunities, the widespread awareness and practice of environmentally-friendly waste management, and improvement of public health and hygiene. This research could only suggest the indication of environmental opportunities resulting from CE integration into MSWM through changes in operational behavior of the sector and suitable WtE adoption. Therefore, further study on other environmental opportunities that CE integration can unlock in the context of KMC will be needed to be conducted. This will require extensive data collection and analysis from all the stakeholders involved in the MSWM of the city. To realize the full potential and effect of CE integration, in KMC particularly, where data concerning MSW is infrequently published or updated and difficult to access, primary data gathering is extremely important, and will be pivotal to further this topic, which was a limitation of this study.

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Appendix

A. List of Abbreviations

3R ....Reduce, Reuse, and Recycle

AD ....Anaerobic Digestion

ADB..Asian Development Bank

CBO..Community-based Organization

CE...Circular Economy

CMU...Community Mobilization Unit

EIA ....Environmental Impact Assessment

GDP..Gross Domestic Product

GHG ....Greenhouse Gas

INGO..International Non-Government Organization

IOC...Indian Oil Company

IPP..Independent Power Producer

ISWM..Integrated Sustainable Waste Management

KMC ....Kathmandu Metropolitan City

KV...Kathmandu Valley

MOFALD ....Ministry of Federal Affairs and Local Development

MOUD ....Ministry of Urban Development

MSW ....Municipal Solid Waste

MSWM...Municipal Solid Waste Management

NEA..Nepal Electricity Authority

NGO ....Non-Government Organization

OFMSW...Organic Fraction of Municipal Solid Waste

PSO ....Private Sector Organization

RDF ....Refuse-derived Fuel

RET...Renewable Energy Technology

SS..Source Segregation

SWM ....Solid Waste Management

SWMTSC ....Solid Waste Management Technical Support Centre

VDC...Village Development Committee

WtE ....Waste-to-Energy

B. Compositions of Household, Institutional, and Commercial Wastes

Table 9. Composition of Household Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

Household Solid Waste Composition (%)	Organic Waste	64.24
	Plastic	15.96
	Paper & Paper Products	8.66
	Glass	3.75
	Metals	1.72
	Textiles	3.4
	Rubber & Leather	1.12
	Others (i.e. Inert Materials)	1.15

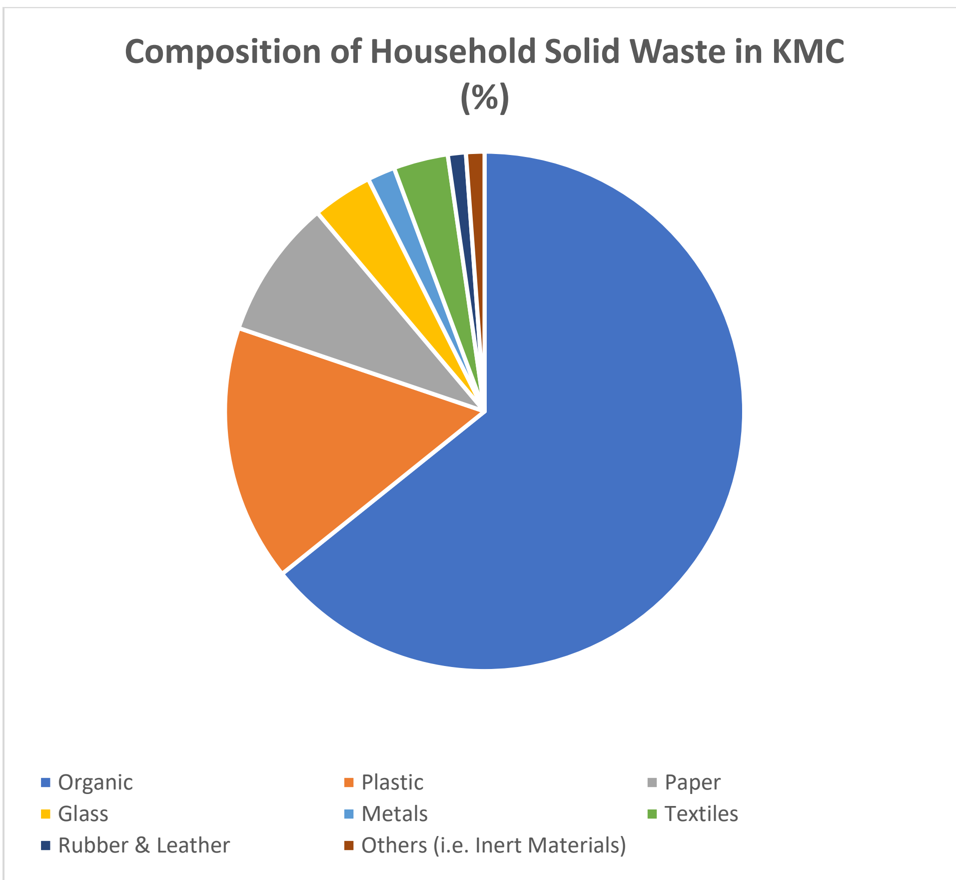

Fig.22 Composition of Household Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

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Table 10. Composition of Institutional Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

Institutional Solid Waste Composition (%)	Organic	20.29
	Plastic	24.55
	Paper	44.28
	Glass	1.37
	Metals	1.13
	Textiles	3.89
	Rubber & Leather	1.14
	Others (i.e. Inert Materials)	3.35

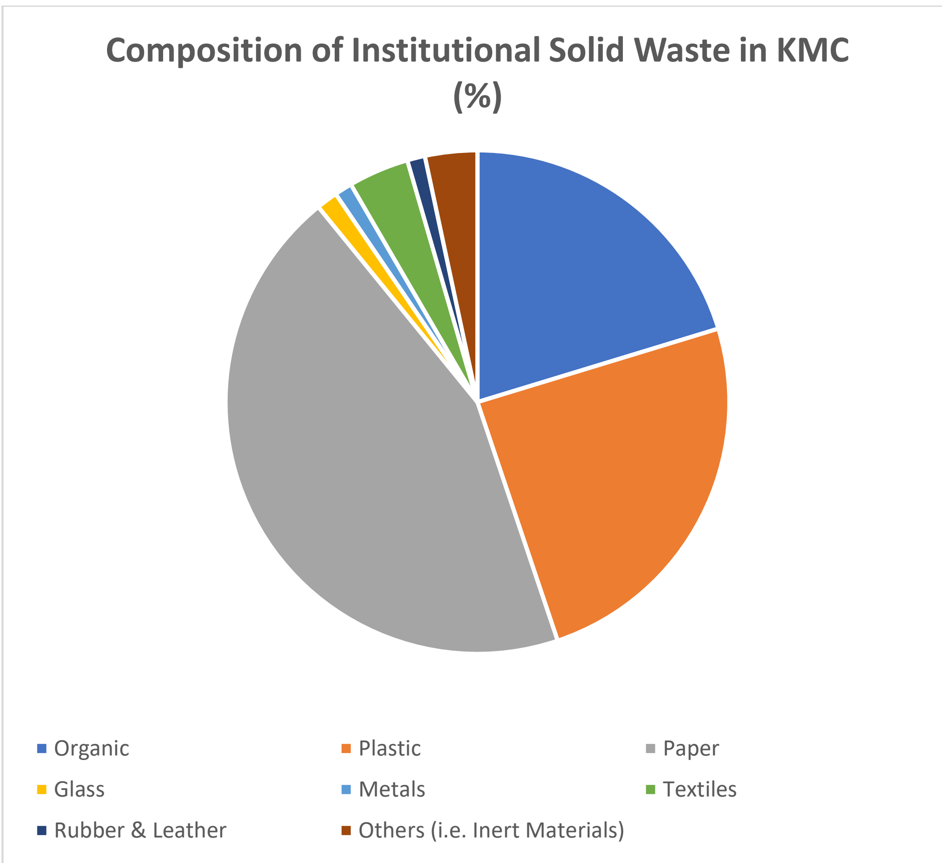

Fig.23 Composition of Institutional Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

Table 11. Composition of Commercial Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

Commercial Solid Waste Composition (%)	Organic	45.44
	Plastic	24.29
	Paper	23.29
	Glass	2.86
	Metals	2.65
	Textiles	1.03
	Rubber & Leather	0
	Others (i.e. Inert Materials)	0.45

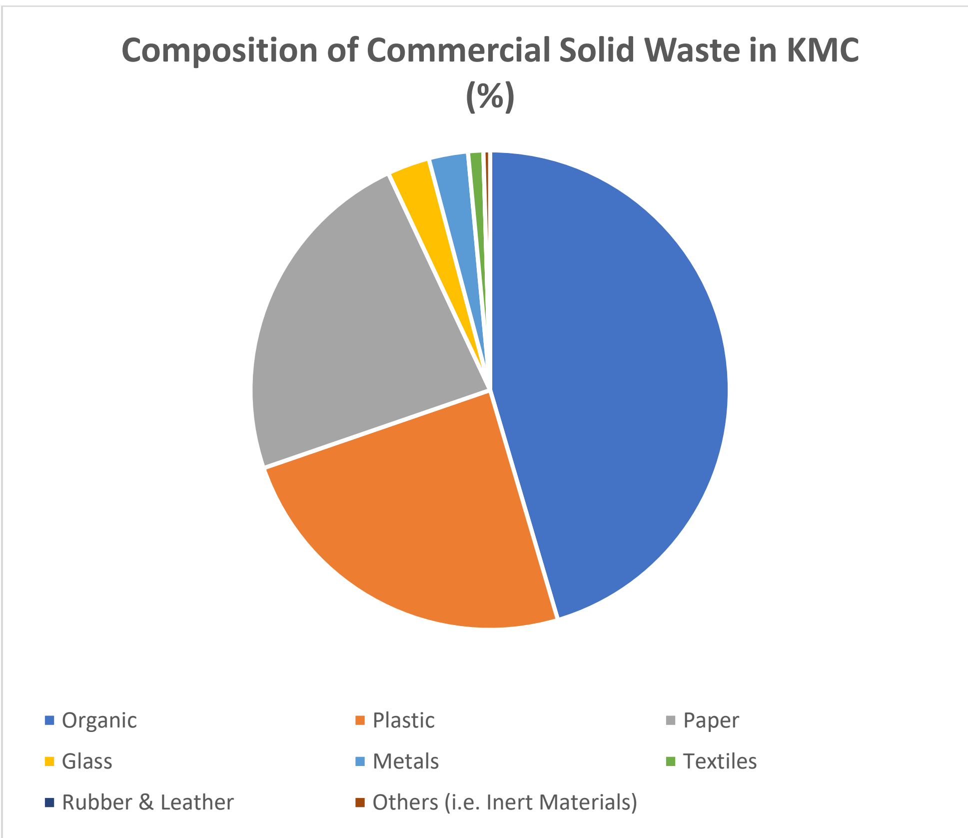

Fig.24 Composition of Commercial Solid Waste in KMC
Source: *(Asian Development Bank, 2013b)*

C. Inventory of MSWM Vehicles & Machinery in KMC

Table 12. KMC MSWM Vehicle and Machinery Inventory. Source: *(Nepwaste, 2018)*

#	Vehicle Types	No. of Vehicles Running	Not functional	Total
1	Container truck	16	1	17
2	Tipper	20	3	23
3	Ambulance	2	3	5
4	Backhoe loader	1	2	3
5	Chinese tractor	2	19	21
6	Compactor	5	7	12
7	Dumper placer	3	9	12
8	Eder Excavator	1	1	2
9	Eicher truck	1	0	1
10	Fecal suction	0	2	2
11	Fiat Allis 10c Dozer	0	1	1
12	Garbage compactor	0	2	2
13	Garbage truck	0	6	6
14	Hanomag Compactor	0	1	1
15	Hermetic self-discharging garbage truck	33	17	50
16	Jetting truck	4	1	5
17	Maruti Gypsy Jeep	1	1	2
18	Mini compactor	1	0	1
19	Road sweeper	1	4	5
20	Road wrecker	1	1	2
21	Self-discharging & loading garbage truck	3	27	30
22	Sewage suction truck	0	2	2
23	Water tank	3	3	6
24	JCB loader	2	0	2
25	Komatsu Dozer D37P-SA	1	0	1
26	Mahindra & Mahindra	0	1	1
27	Mercedes Benz Miller Truck	0	1	1
28	Rocsta Jeep	0	1	1
29	Shovel loader	0	1	1
30	Skid steer loader	0	2	2
31	Suction Tanker	1	0	1
32	Suction Truck	0	4	4
33	Tata mobiles	1	1	2
34	Tata safari	1	0	1
35	Tata truck	2	0	2
36	Truck	1	0	1
Total		**107**	**124**	**231**