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Assessment of Integrated Solid Waste Management Systems in Kathmandu Metropolitan City

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Abstract

One of the main challenges in developing countries like Nepal is inefficient management of municipal solid waste. Provision of fundamental services for municipal solid waste management is a major concern in urban areas of Nepal, especially in the capital Kathmandu Metropolitan City (KMC). The formal waste management system of KMC is limited to collection and disposal in landfill site or open dumping. Intermediate steps are not opted formally for resource recovery or treatment of the waste. In view of the challenges encountered, the Asian Development Bank has recommended adopting integrated solid waste management. The study aims at developing and accessing scenarios for integrated solid waste management that is pertinent to the case of KMC. The specific objectives include defining different integrated solid waste management systems and determining their energy recovery and material recovery efficiencies. The first waste management system is material recovery-based system. The second waste management system is energy and material recovery-based system. Additionally, a SWOT (strengths, weaknesses, opportunities, and threats) analysis of the two proposed waste management systems was carried out to recommend the more appropriate system, in the context of KMC. Results of the study depicted that material recovery efficiency of the second system is lower than the first system, however, the electrical energy efficiency is especially prominent for second system. Based on the results of material and energy recovery efficiency calculations and the outcomes of the SWOT analysis, adoption of the material and energy recovery based waste management system is found to be instrumental for efficient management of municipal solid waste in the context of KMC. In view of the negative impacts imposed by the current improper municipal solid waste management in KMC, implementation of the material and energy recovery based integrated solid waste management system will be beneficial in not only effectively managing the municipal solid waste but also provide resources by recovering material and energy from the waste generated. However, if following the waste hierarchy, the material recovery based system would be preferable. In the short term, the energy and material recovery-based system may be considered. But risks of technological lock-in effects in the long term can be detrimental in realizing and taking advantage of the material recovery potentials.

Keywords: *Integrated solid waste management; material recovery; energy recovery; circular economy.*

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1. Introduction

One of the main challenges in developing countries like Nepal is the inefficient management of municipal solid waste. According to the World Bank (2013), the population of KMC is 2.5 million and it is increasing with an annual growth rate of 4.78% and KMC is the highest expanding metropolitan region in South Asia. The rapid urbanization followed by exponential increase in the population have contributed to the massive surge in the Municipal Solid Waste (MSW) generated. Provision of fundamental services like municipal solid waste management (MSWM) is a major concern in many urban areas of Nepal, especially the capital i.e., Kathmandu Metropolitan City (KMC). The formal waste management system of KMC is limited to collection of MSW and direct disposal in the landfill site or even open dumping (SWM Act, 2011). Segregation of recyclables from the solid wastes are performed informally by private sectors and waste pickers (or scavengers) that are sold either to local small-scale recycling centers in Nepal or exported to India (ADB, 2013). However, no intermediate steps are opted formally for resource recovery or treatment of the waste (ADB, 2013). Such inefficient and unsanitary waste management system of KMC can be attributed to various factors such as low prioritization of MSWM, lack of technical, financial, and institutional capacity, along with lack of public awareness, weak law enforcements and political instability in the country (Lohani et al., 2021; Dangi et al., 2017; ADB, 2013). Therefore, efficient municipal solid waste management had become imperative for the welfare of KMC. The MSW collection rate of KMC is 86.9% and the waste composition signifies that the organic fraction of waste constitutes the highest proportions (43%) which is followed by paper (25%), plastic (22%), textiles (3%) and glass (3%) (ADB, 2013). Other wastes such as metals, rubber and leather waste constitute of about 4% of the MSW composition (ADB, 2013). The waste fraction of KMC has reflected on the potential of recovering valuable materials from the MSW. However, due to lack of effective MSWM system, these valuable materials are dumped instead, adding burden on the limited space of landfill. In view of the key challenges encountered by the waste management systems of Nepal, ADB (2013) have recommended integrated approach that needs to be adapted for the different functional units of MSWM from segregation at source till resource recovery and final disposal. The study aims to develop and assess scenarios of integrated solid waste management system that is pertinent to the case of KMC. The specific objectives include defining different integrated solid waste management systems and determining their energy recovery and material recovery efficiencies. Additionally, a SWOT (strengths, weaknesses, opportunities, and threats) analysis of the proposed waste management systems will be carried out to recommend the more appropriate system, in the context of KMC. The primary focus of the study is the technological feasibility of different waste management scenarios pertinent in the context of KMC, however, the SWOT analysis will contribute the addressing the alignment between technological, policy and environmental considerations that are required for efficient operation of the proposed integrated solid waste management system. Hence, the study focuses on the broader scope of integrated solid waste management which includes socio-technical approach that incorporates functional units of waste management, stakeholders, and sustainability aspects.

2. Material and methods

An integrated solid waste management system pertinent for KMC has been defined that aims in treating diverse types of wastes by combining different types of technological options (Memon, 2010). The waste management systems defined are Waste Management System 1 (WMS1) (i.e., material recovery based system) and Waste Management System 2 (WMS2) (i.e., material and energy recovery based system). Using data of MSW collected and its composition (ADB, 2013), the quantity of wastes generated for each waste component was determined as tonnes per day. For WMS1, materials and nutrients are modelled to be recovered by recycling and composting, respectively. In WMS2, materials are modelled to be recovered by recycling of recyclable fraction of waste and nutrients are modelled as recovered from biogas slurry of the anaerobic digestion process. Nutrients are modelled to be recovered as tonnes of nitrogen (N), phosphorous (P), and potassium (K) in both the proposed systems. The recyclable fraction of waste includes paper, plastic, textiles, glass, metals, rubber and leather. Furthermore, energy is modelled to be recovered in WMS2 by anaerobic digestion of organic fraction of waste and (Waste to Energy) WtE incineration technologies for non-recyclable fraction of waste that are combustible (paper and paper products, plastics, textiles, rubber and leather). The non-combustible inorganic wastes that could not be recycled (metals and glass) are modelled to be disposed in the sanitary landfill. The energy recovery system in this study is concentrated on electricity generation only and not on combined heat and power (CHP) generation. Details on the considered waste management systems have been shown in Figure 1. The nutrient recovery by composting was determined as the product of dry matter (DM) (calculated as the product of organic waste generated and the moisture content) and nutrient content (% of DM) (BMEL, 2015). The materials recovered by recycling is determined as a product of the estimated MSW of each waste component and their recycling rates. The recycling rate of each recyclable waste component was compiled through literature (Wecker, 2018; European Environment Agency; FEVE, 2015). Total materials recovered in WMS1 was calculated by combining the materials recovered from inorganic fraction of waste and nutrients recovered from organic fraction of waste. The material recovery efficiency is calculated as percent of total materials recovered from the estimated municipal solid waste that is collected.

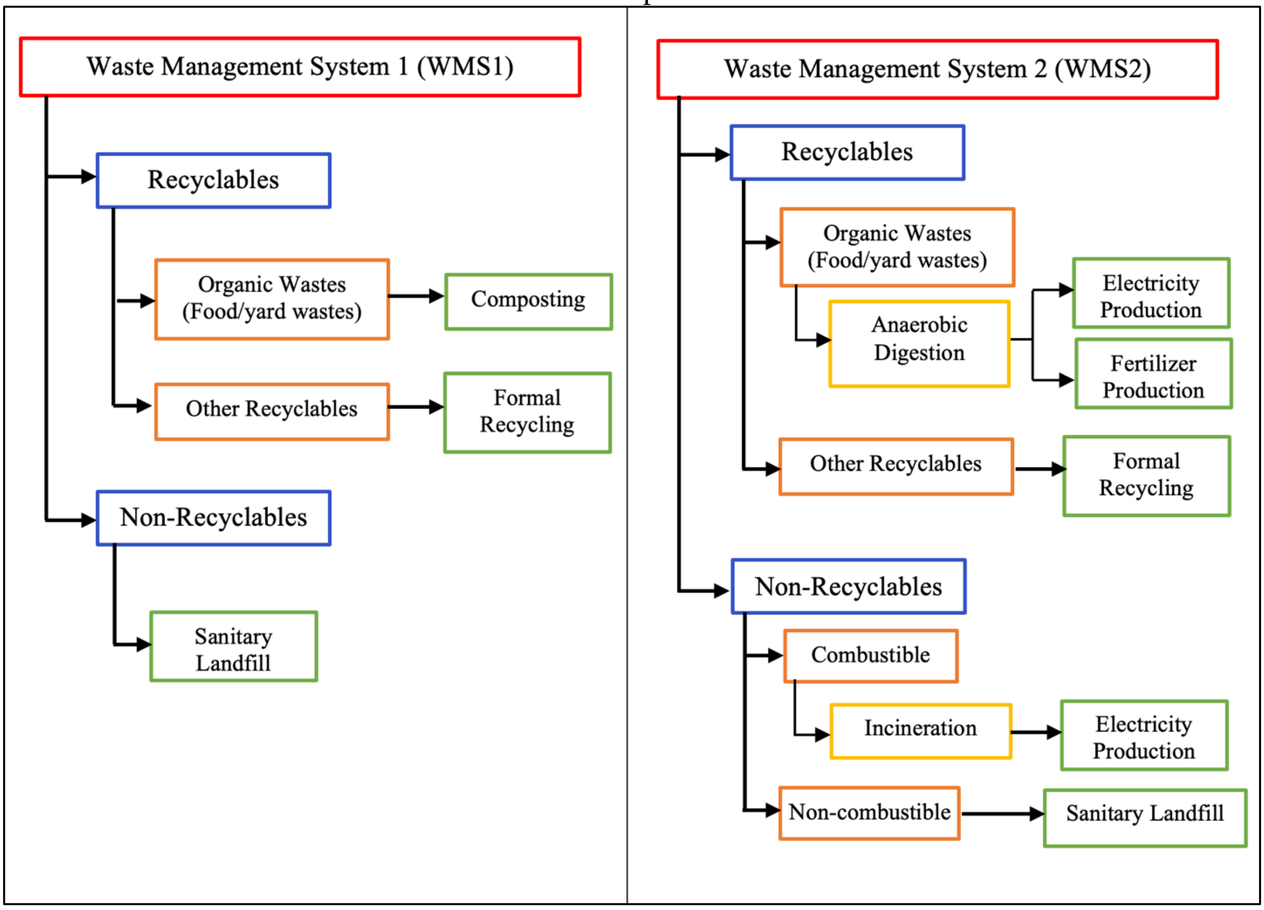

Figure 1 Flow Diagram of Waste Management Systems considered

Total materials recovered WMS2 was calculated by combining the material recovered from recycling and as nutrients recovered from biogas slurry. The nutrient recovered from biogas slurry is estimated in the same manner as WMS1. The materials recovered by recycling in WM2 is determined by the same method as on WMS1, but the recycling rate is taken as the average recycling rate in Nepal i.e., 21% for all waste components (Timilsina, 2001). The calculations for anaerobic digestion encompass estimating the biogas and methane (CH_4) production, electricity generation and nutrient recovery from biogas slurry (AEPC, 2019; Christensen, 1998; BMEL, 2015). The electricity generation potential from anaerobic digestion was estimated as a product of total biogas yield of organic waste (m^3/day), electricity generation per m^3 biogas (kWh/m^3) and methane in biogas (%) (Poulsen & Kuligowski, 2007; Prapaspongsa et al., 2009). The electricity generation potential from WtE incineration was calculated as the product of energy content in MSW and electricity production efficiency of incineration plant, i.e., 38% (Poulsen & Kuligowski, 2007). The energy in MSW (except recyclables and organic waste) was calculated by determining the dry weight using moisture content values, followed by determining the energy content (MJ) using heating value (MJ/kg) of each waste component (Tchobanoglous, 1993). Energy recovery efficiency of WMS2 was calculated by combining the potential electrical energy recoverable from anaerobic digestion and incineration of MSW. Additionally, SWOT analysis was implemented to evaluate the two proposed waste management systems (Xiao et al., 2020). Based on the outcome of the SWOT analysis, the most appropriate waste management system pertinent to KMC will be recommended.

3. Results and discussion

The estimated MSW collected in KMC has been presented in Table 1. The estimation of nutrient and material recovery for WMS1 has been depicted in Table 2. The material recovery efficiency of WMS1 is 35.6%. The estimation of energy, nutrient, and material recovery for WMS2 has been depicted in Table 3. For WMS2, the material recovery efficiency is 11.83% and the energy recovery efficiency is 45.86%. Therefore, WMS2 has the potential of recovering both energy and materials from the MSW of KMC. Although the material recovery efficiency of WM2 is lower than WM1, the electrical energy efficiency is especially prominent for WM2 (Figure 2).

In WMS1, MSW that cannot be recycled are modelled as sent to the sanitary landfill for final disposal. While in WMS2, the non-recyclables will not be directly sent to the sanitary landfill, unlike WMS1. The non-recyclables along with the organic wastes are modelled as further treated to recover energy. Hence, in WMS2, both material and renewable energy are recovered from the MSW. The non-combustible wastes that could not be recycled (metals and glass) are modelled as disposed in the sanitary landfill. Details on the SWOT analysis have been shown in Table 4.

Table 1 Estimated MSW collected in KMC

Parameter	Value	Unit
Total MSW Generated	466.14	tonnes/day
Collection efficiency	86.9	%
Estimated MSW Collected	405.08	tonnes/day

Table 2 Estimated Material Recovery by WMS1

Parameter	Value	Unit
Nutrients recovered by composting	1.98	tonnes/day
Materials recovered by recycling	142.07	tonnes/day
Total materials recovered	144.04	tonnes/day
Material Recovery Efficiency	35.6	%

Table 3 Estimated Material and Energy Recovery by WMS2

Parameter	Value	Unit
Nutrients recovered from biogas slurry	1.08	tonnes/day
Materials recovered by recycling	46.83	tonnes/day
Total materials recovered	47.91	tonnes/day
Material Recovery Efficiency	11.83	%
Energy recovered by anaerobic digestion	40.47	MWh/day
Energy recovered by WtE incineration	452.11	MWh/day
Total energy recovered	492.58	MWh/day
Potential Electrical Energy in MSW	1074.2	MWh/day
Energy Recovery Efficiency	45.86	%

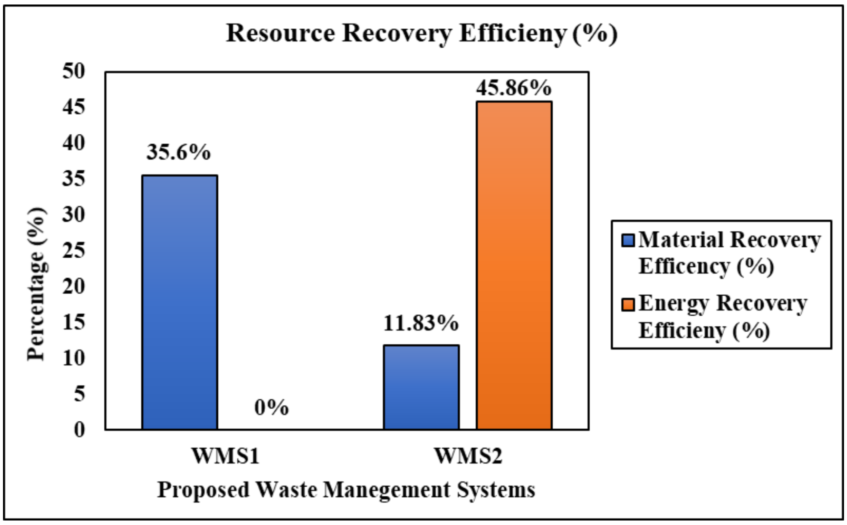

Figure 2 Results of the Resource Recovery Efficiencies

Table 4 SWOT Analysis of proposed waste management Systems

SWOT	WMS1	WMS2
Strength	High material recovery efficiency (for recyclable materials).	Resource recovered as both energy and materials.
	Relatively low investment required in composting.	Follows waste hierarchy i.e., 3R (waste reduction, reuse, and recycle).
	Decrease on dependency on chemical fertilizers and virgin raw materials.	Large quantities and diverse wastes of KMC can be treated.
Weakness	Impracticable recycling rates that is difficult to achieve.	High investment requirements for establishing comprehensive facilities.
	Larger amounts of waste still entering landfill.	Proposed technologies are highly complex and advanced requiring extensive technical and institutional capacities.
	Odor and leachate problem from compost plants.	Large space requirement for establishing the plants.
Opportunity	Improvement in the economic status of informal waste pickers.	Help in strengthening the legislations related to MSWM
	Increase in agricultural productivity.	Skill enhancement opportunity due to introduction of advanced technologies.

Table 4 SWOT Analysis of proposed waste management Systems (Continue)

SWOT	WMS1	WMS2
Threat	Creates employment and business opportunities. Inefficient enforcement of national policies and regulations. Inefficient waste segregation resulting in mixed collection of waste. Inability to establish end-user industry and market for recycled materials and compost.	Creates employment and business opportunities. Inefficient enforcement of national policies and regulations. Required waste quantities for WtE is not guaranteed. Release of harmful toxins in the atmosphere and improper management of Air Pollution Control (APC) residues and bottom ash from WtE incinerator.

The recycling rates used in WMS1 are referred from the context of recycling rates achieved by European countries. The material recovery efficiency was found to be 35.6%, which are highly ambitious for KMC. Attaining such level of detailed planning throughout the supply chain will be extremely challenging. In comparison to WM1, only 11.83% materials can be recovered in WMS2. Furthermore, in WMS2 resource are modelled to be recovered not only as materials but also as energy in the form of electricity. Based on the results of material and energy recovery efficiency calculations and the outcomes of the SWOT analysis, adoption of WMS2 will be beneficial in handling the current improper and unsanitary MSWM of KMC. For the sustainable implementation of WMS2, it is imperative to follow the waste hierarchy. Firstly, effort on proper segregation of the different waste components is crucial for successful execution of WMS2. Energy and nutrient recovery are complementary for the treatment of organic fraction of waste through the anaerobic digestion technique. However, for the treatment of remaining fraction of waste (i.e., paper and paper products, plastics, metals, glass, textiles, rubber, and leather), it is essential to follow waste hierarchy. Although, WtE incineration facilitates reduction of waste volume after treatment and subsequently electricity generation, the WtE incineration should not compete with waste reduction, reuse, and recycle (Liu et al., 2020). The calculation showed that waste composition of KMC has good energy generation efficiency, but it should not be prioritized over recycling. Hence, WMS2 is advisable when material recovery by recycling is prioritized over energy recovery by WtE incineration. For the efficient implementation of the WMS2, the following recommendations have been proposed:

- Source segregation should be prioritized to create value for recovered materials and collection should be carried out regularly.
- Collaboration between government and private sector is required on formalizing recycling by issuing official license, such that the private sector can formally employ the informal waste pickers in collecting segregated waste.
- Incentives should be provided to private businesses in establishing recycling centers for different types of waste components. Incentives such as providing government owned land free of cost, low interest rates on loan, moderation in tax imposed on importing equipment can be initiated.
- Establishing synergy between various key stakeholders like informal waste pickers, waste buyers, intermediate dealers, recycling industries and end-user industries of recycled materials is vital for increasing the recycling rates.
- Specific guidelines related with the quality and safety requirements of the organic fertilizers must be imposed in order to commercialize the fertilizers derived from biogas slurry (BMEL, 2015).

- Installing flue gas treatment facility should be prioritized when constructing a WtE incineration plant. APC residue and bottom ash must be disposed carefully in landfill.
- Initial consultation on capacity building from developed countries can be helpful to attain guidance on integrated solid waste management system.
- As construction of WtE plants require high investments, providing incentives to private investors inclined towards this technology will be beneficial.
- Creating market for side products are important as well, so provision of electricity feed-in-tariffs, subsidies, and incentives for soil improvement (digestate) products should be considered.
- The government must establish institutions with the responsibility of research and development in the field of integrated solid waste management. Calculations of the study was based on data from the year 2013, which underestimate the quantity of MSW. Regular updated baseline information on MSW characteristics needs to be efficiently disseminated amongst stakeholders.
- Cooperation between the concerned governmental bodies i.e., MSWM Technical Support Center (SWMTSC) and Alternative Energy Promotion Center (AEPC) is required to develop policies on distribution of the generated electricity that is connected to the national grid.
- To execute the abovementioned recommendations, it is crucial for the government to enforce stringent regulations (placing waste hierarchy as foremost priority) that are adhered to and monitored periodically.

4. Conclusions

The existing waste management system in KMC lacks formal recycling facilities, or any waste treatment activities like energy recovery facility, and most of the waste is disposed directly in landfill site. The waste composition data of KMC has reflected on the potential of recovering valuable materials from the municipal solid waste. There current inefficient operation of municipal solid waste management system in KMC calls forth for the amelioration of the existing system, which will ultimately lead to the holistic enhancement of the environment, public health, and the economy. In view of the negative impacts imposed by the current improper municipal solid waste management in KMC, implementation of the material and energy recovery based integrated solid waste management system will be beneficial in not only effectively managing the municipal solid waste but also provide resources by recovering material and energy from the waste generated. However, if following the waste hierarchy, the system based on material recovery would be preferable. In the short term, the energy and material recovery-based system may be considered. But risks of technological lock-in effects in the long term can be detrimental in realizing and taking advantage of the material recovery potentials.

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