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Electricity Generation Potential of Municipal Solid Waste of Nepal and GHG Mitigations

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Abstract: This research is carried out to assess the current status of municipal solid waste of municipalities of Nepal and its potential for energy recovery. During the year 2016, solid waste samples were collected by door-to-door collection method and the total energy content of the municipal waste was calculated using Bomb Calorimeter in the laboratory. During the study period, the total waste generated at Kathmandu metropolitan city was 566 tons per day with 0.3 kg per capita contribution. The major waste constituent was the organic with 67.77% of the total waste volume. Other bulk wastes were plastic and paper constituting 10% and 5% by volume respectively. Rest of the wastes (8%) was categorized as "other". In average, the total moisture content in the wastes was 49.93%. Total waste generation of all municipalities was found 1435 tons per day. The calorific value of the plastic wastes had highest energy content (40.61 MJ/kg). The organic (15.68 MJ/kg) and paper (15.61MJ/kg) wastes had similar energy content while the other wastes had slightly higher energy content (17.57MJ/kg). The net energy available and, thus, lost after dumping of the solid waste was 71,895,056 MJ which is equivalent to 4262 MWh which can run 52 MW plasma arc gasification power plant. The waste to energy potential of Kathmandu Metropolitan city was found to be 19 MW. Total reduction in GHG emission was found 220,690 kg CO_2 eq kg per day.

Keywords: Electricity Potential, Waste to Energy, GHG Mitigation

1. Introduction

The problems arising from solid waste can be solved by using innovative technologies. Nowadays, different types of waste-to-energy (W-T-E) schemes are available through which energy can be efficiently recovered and used, such as anaerobic digestion (i.e. both dry and wet, thermophilic and mesophilic), thermal conversion (i.e. rotary kiln incineration, mass burn incineration, starved air incineration, fluidized bed combustion, pyrolysis and gasification, plasma technology, thermo-chemical reduction, refuse derived fuel) and landfilling (i.e. landfill gas utilization and bioreactor landfill). Each type of technology handles the specific composition and quantity of solid waste [7]. It seems to be difficult to propose suitable waste management plans and technologies without determining the quantity and composition of generated waste [4].

Over long run, both the Gases; Methane and Carbon dioxide pose serious threat to global warming. Researchers have already proved Carbon dioxide as prime cause of global warming but recently we have begun to understand the role of Methane. But due to relatively short life time of about 12 years, we have not given considerable attention but the studies from United Nations Framework Convention on Climate Change (UNFCCC) fourth assessment report confirms methane to be 25 times more effective at trapping heat in the atmosphere when compared to Carbon dioxide over a 100 year time period. The major sources of emission of methane in the atmosphere come from microbial decomposition in anaerobic environment of Lakes, paddy fields and municipal waste dumping sites [2].

As municipal dumping site is one of the sources for emission, it should be noted that these emission sites are confined to definite area thus we could rather harvest the gas for commercial use. The use on the one hand checks the emission while on the other hand benefits economically.

2. Solid Waste Management in Nepal

The maximum waste generated in Nepal is in the capital city itself. Kathmandu municipality generates about 566 tons of waste each day. This figure is more than 3.5 times the waste generated in Pokhara which is next in the list with 117 tons a day. Similarly, Lalitpur Sub Metropolitan generates 84 tons of waste per day and is the third largest. In contrast, Dhulikhel and Bhadrapur produce the least waste per day with the figure of under 3 tons each day. Next in the list are Bhimeshwor, Jaleshwor, Narayan, and Amargadhi municipalities all with the generation less than 3 tons a day as shown in Fig. 1.

According to the base line study done in year 2016, the average per capita household waste generation rate in Kathmandu is 0.3 kg/person/day. This is similar to the average waste generation rate in urban areas of Nepal which is 0.25 kg/person/day considering the total populations of Kathmandu Metropolitan City in 2016 to be 2,100,000; the total amount of municipality waste generated comes out to be 566 ton per day. Population growth rate of the city is 4.35 % in 2016; this high growth rate is expected to increase the waste generation at even higher pace [5].

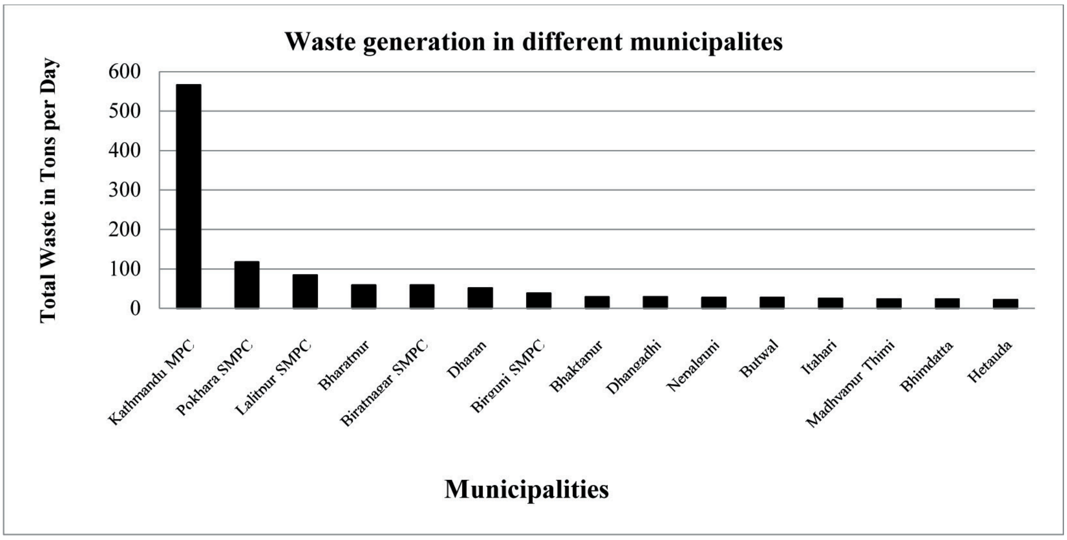

Fig. 1: Waste generation of different Municipalities of Nepal (source: solid waste management technical support center, 2016)

3 Methodologies

3.1 Moisture Content in Waste

The sample was categorized into five strata: organic wastes, paper wastes, plastics wastes, other wastes (contained textile wastes, dusts, electronic wastes) and noncombustible wastes (merged group of metals and glass).Once the moisture content of the sample was defined, this was integrated into total waste and total moisture content and dry weight of the sample was drawn. This is important finding for the use of these MSW into waste to energy conversion system because moisture content is an important determinant factor in the energy content of waste substance. Moisture content is calculated as

$$Moisture\ Content\ =\ \frac{Total\ moisture\ weight}{total\ municipal\ waste\ weight} X100 \quad (1)$$

3.2 Calorific Value Determination

Using bomb calorimeter, we get the high heating value of the fuel. To get the LHV, the molecular formula for the fuel must be known. This is obtained by the ultimate or elemental analysis. Lower heating value of samples was determined as the energy required to completely dry out the moisture content of the wastes were subtracted from gross calorific value of the wastes [3].

3.3 Calculating Energy Efficiency of Energy Conversion System

Here municipal solid waste is considered to be used without dried in the sun. The following equation is adapted from [6]

$$Ed\ =\ HI\ +\ HV \quad (2)$$

But the energy required for drying MSW to a constant weight (Ed) is given by the sum of the energy required to raise the temperature of the water in waste from its initial temperature to a vaporization temperature of 100°C (HI) and the energy required to completely vaporize the water in the waste at 100°C or heat of vaporization (HV).

This means that

$$Ne\ =\ Gte - (HI\ +\ HV) \quad (3)$$

Therefore, equation (1) becomes,

$$HI\ =\ m\ \times c\ \times\ \theta \quad (4)$$

But *HI = mass (m)* of moisture in *MSW* x heat capacity (c) of water in *MSW* x change in temperature (θ).

This implies that

$$HV\ =\ m\ \times\ cV \quad (5)$$

But, θ = final temperature (100°C) – initial temperature of water in MSW assumed to be the average annual temperature in Municipality.

And HV = mass (m) of moisture in MSW x latent heat of vaporization (cV). This also implies that

$$Ne = Gte - (m \times c \times \theta + m \times cV) \quad (6)$$

Therefore, equation (3) becomes

Energy efficiency of an energy conversion program

$$\eta = \frac{Ne}{Gte} \times 100\%. \quad (7)$$

The potential net maximum recoverable energy depends largely on inherent physical characteristics such as moisture content and heating value of urban refuse in a given waste stream.

3.4 Estimating the Energy Potential of MSW

After getting the calorific value of each categories of waste, the total energy potential of MSW was calculated [8]

$$Total\ Energy = \sum W_i \times CV_i \quad (8)$$

3.5 GHG Calculations

GHG mitigation by the waste to energy was calculated using following formula [1]:

$$GHG\ mitigation = \sum (W_i\ X\ MF_i) \quad (9)$$

4 Results and Discussion

4.1 Solid Waste Generation

According to the demographic records of the Municipalities of Nepal, the average number of persons per household was 5.4. The average household solid waste generation was calculated to be 0.80 kg/day.

Table 1: Generation of solid waste

Average HH waste (kg/day)	0.80
Average HH size (numbers of Members)	5.4
Average per capita HH Waste (g/capita/day)	170
Total HH Waste (tons/day)	770
Total Commercial Waste (tons/day)	447
Total Industrial Waste (tons/day)	65
Average per capita MSW (g/capita/day)	317
Total MSW Generation(Tons/day)	1,435
Total Estimation Collection of Waste (tons/day)	822

Fig. 2 shows the composition of waste of municipalities of Nepal. Organic wastes were the most abundant ones sharing 62 % of total, while plastics and papers shared 11% and 10%. All other wastes shared only 17% of total waste.

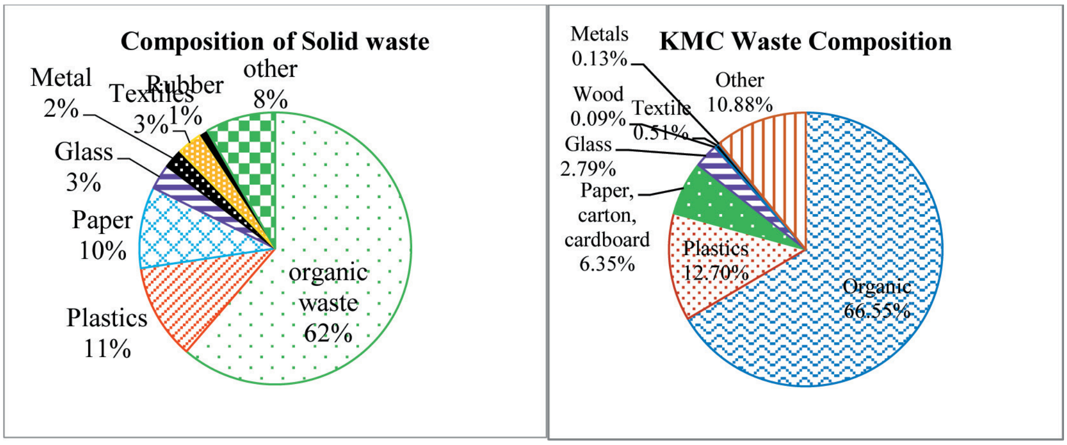

Fig. 2: Percentage share of total waste of municipalities of Nepal

The municipal solid waste of Kathmandu metropolitan city contains 67 % organic waste, the share of plastic waste is 13 % and, waste contains 6.35 % paper waste and others contain 11 % waste. The municipalities of the mountain region contain 51 % of organic waste of total generated waste. Plastic and paper waste have equal share of 11% of total waste as shown in Fig. 3.

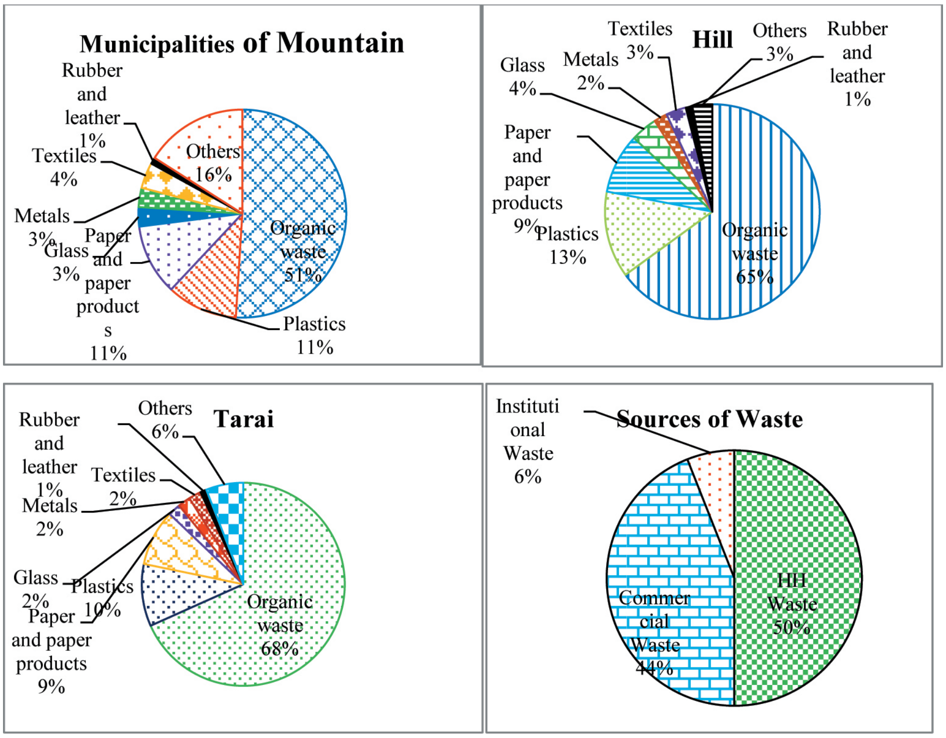

Fig. 3: Composition of solid waste of municipalities of mountain, hill and Terai region and Sources of waste

The municipalities of the hilly region contain 65 % of organic waste of total generated municipal solid waste. The share of plastic and paper waste is 13% and 9 % respectively. The municipalities of the Tarai region contain 68 % of organic waste of total generated municipal solid waste. The share of plastic and paper waste is 10% and 9 % respectively.

The main source of the municipalities is house hold which produces nearly 50 % of solid waste then commercial sector produces 44 % waste and institutional waste production is nearly 6 % of total solid waste generation as shown in Fig. 3.

4.2 Moisture Content of the Wastes

With the use of oven, at constant temperature of 85^{0}C, moisture content was determined for pre-defined categories. After the determination of moisture content, the dry weights were extrapolated to get the moisture content in the total municipal solid waste.

Table 2: Percentage of moisture content of the MSW

Type of waste	Quantity of waste (kg)	Dry weight (kg)	Moisture Content (kg)	Moisture content (percentage)	Dry weight (percentage)
Organic	1	0.3	0.7	70	30
Plastic	1	0.95	0.05	5	95
Paper	1	0.8	0.2	20	80
Other	1	0.9	0.1	10	90

The total weights of moisture content of municipal wastes of Kathmandu Metropolitan City are given in the Table 3

Table 3: Total weight of moisture content in MSW

Type of Waste	Total Municipal Waste (kg)	Moisture Content (Percentage)	moisture Weight (kg)	Dry weight (kg)
Organic	376,673	70	263,671	113,001
Plastic	71,882	5	3,594	68,288
Paper	35,941	20	7,188	28,753
Other	81,581	10	8,158	73,423
Total	566,077		282,611	283,465

4.3 Energy Evaluation of Waste

The average energy content of these wastes is presented in Table 3. Among all categories, plastics have highest energy content and category organic has second most energy content in the waste stream. Paper and organic wastes have similar energy content per kg; however, high volume in the waste composition for organic waste has more contribution in energy content of overall MSW.

Table 4: Total energy content of MSW

S.N.	Type of waste	Dry weight in kg	MJ of Energy per kg	Total energy of MSW (MJ)
1	Organic	113,001	15.68	1,771,870
2	Plastic	68,288	40.61	2,773,171
3	Paper	28,753	15.64	449,694
4	Other	73,423	17.55	1,288,572
Total				6,283,307

Gross total energy (Gte) in the municipal solid waste was found to be 6,283,307 MJ. But this did not consider the heat required to convert moisture content in the waste to gas, *i.e.* Ed. Because, during conversion of waste to energy, all the wastes are accepted in the wet state and there is certain energy required to dry out that moisture from the waste to be able to accept as fuel. Thus, it is needed to subtract latent heat of vaporization from the gross total energy. This is also called as Net total energy (Ne).

The average annual temperature of Kathmandu metropolitan is taken as 15^0C for the calculation of net energy. Specific heat capacity of water is 4.2 KJ/kg/ ^{o}C, i.e. 0.0042 MJ/kg/ ^{o}C and latent heat of vaporization of water is 2.44 MJ/kg. The gross total energy of the waste is 8.99 MJ/kg while net energy is found to be 7.46 MJ/kg. Therefore, 1.53 MJ/kg of energy is lost during moisture liberation. Hence, of the total energy, only 82.93% is available and the rest of the energy (17.17%) is lost due to moisture.

If this waste is consider as a waste to energy resource for incineration, we could produce 35 MW of electricity. The electricity potential of Kathmandu metropolitan city is 14 MW from daily waste.

4.4 Energy Potential of major Municipalities of Nepal

The graph shows the energy potential of major Municipalities of Nepal. It can be observed that the most potential of the municipalities is Kathmandu with 1745 MWh followed by Lalitpur Sub Metropolitan City at 278 MWh, Pokhara at 244 MWh. The least of the municipalities considered was that of Bhadrapur at 5.3 MWh.

The graph shows the size of the power plants that can be established in the major municipalities of Nepal. It can be observed that the capacity of the plant at Kathmandu is 14.39 MW followed by Lalitpur at 2.3 MW, Pokhara at 2 MW. The lowest is that of Bhadrapur at 44.35 KW.

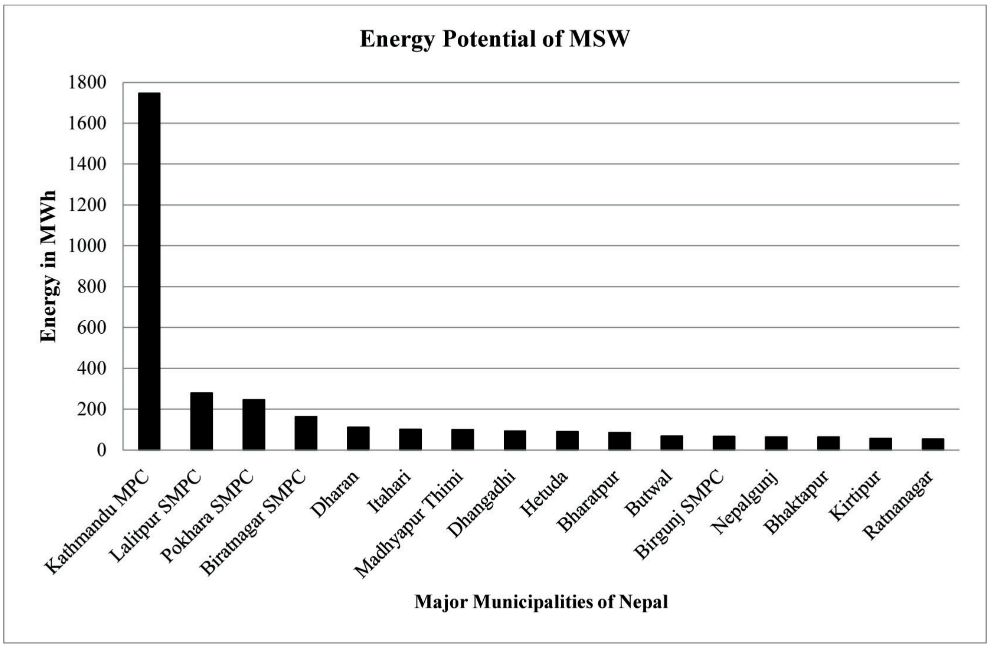

Fig. 4: Energy potential of MSW

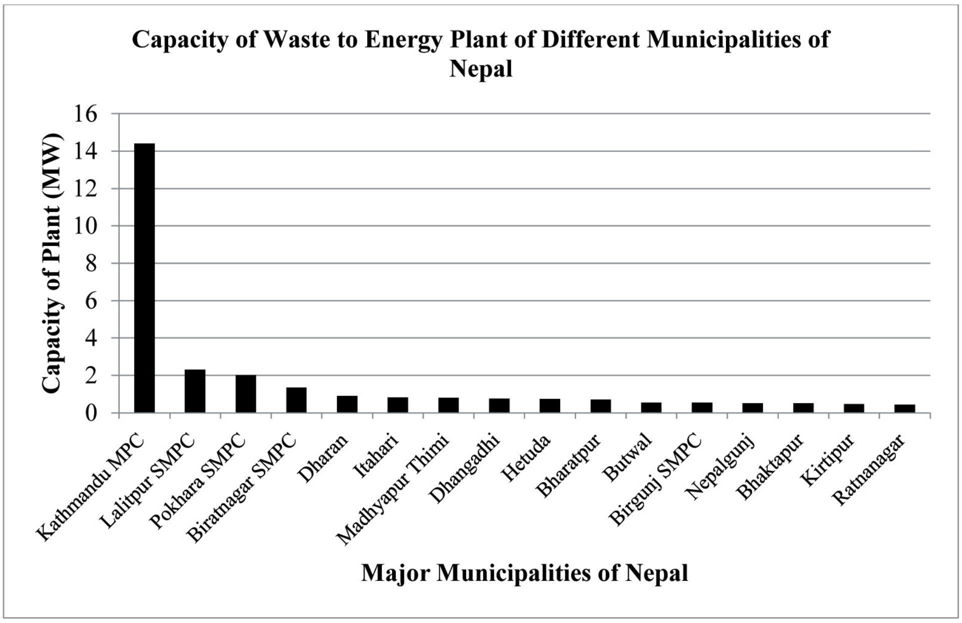

Fig. 5: Waste to energy capacity

4.5 Capacity of Different WTE Technologies

The capacity of plasma Arc gasification technology can produce 19.22 MW electricity from municipal solid waste of Kathmandu Metropolitan City. Similarly conventional gasification, pyrolysis and incineration technology can produce 16.154MW, 13.465MW and 12.83 MW respectively as shown in Fig. 6.

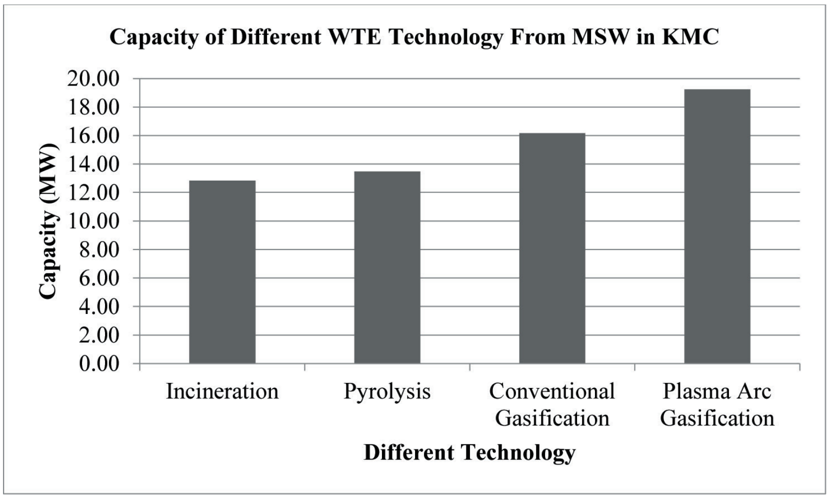

Fig. 6 : Capacity of different WTE technology for KMC

The total capacity of these technologies for all municipalities is shown in following graph. The total capacity of plasma arc gasification is 52.2 MW. Similarly conventional gasification, pyrolysis and incineration technology can produce 3.8 MW, 36.5 MW and 34.8 MW respectively as shown in Fig. 7.

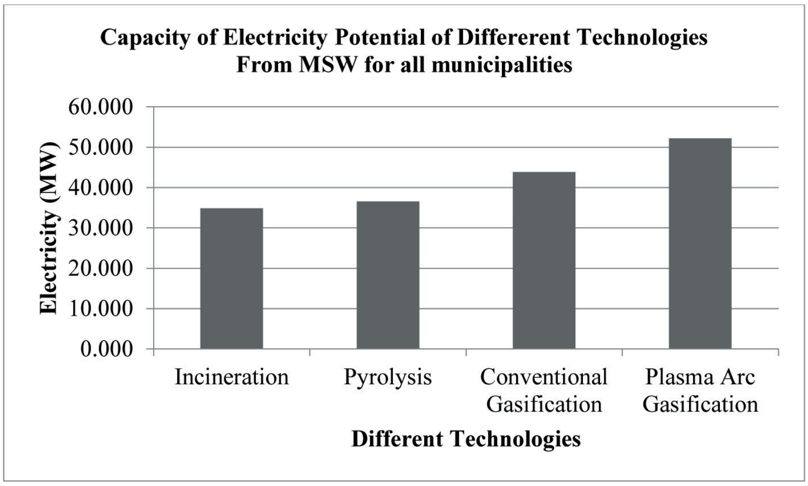

Fig. 7 : Capacity of different WTE technologies for all municipalities

Fig. 8 shows the capacity of different WTE technologies for major municipalities of Nepal. The capacity of plasma Arc gasification technology can produce 19.2 MW electricity from municipal solid waste of Kathmandu Metropolitan City. Similarly, conventional gasification, pyrolysis and incineration technology can produce 16 MW, 13.5 MW and 12.8 MW respectively. Similarly capacity of plasma Arc gasification technology can produce 4 MW electricity from municipal solid waste of Pokhara sub-Metropolitan City. Similarly conventional gasification, pyrolysis and incineration technology can produce 3.3 MW, 2.8 MW and 2.6 MW respectively for Pokhara.

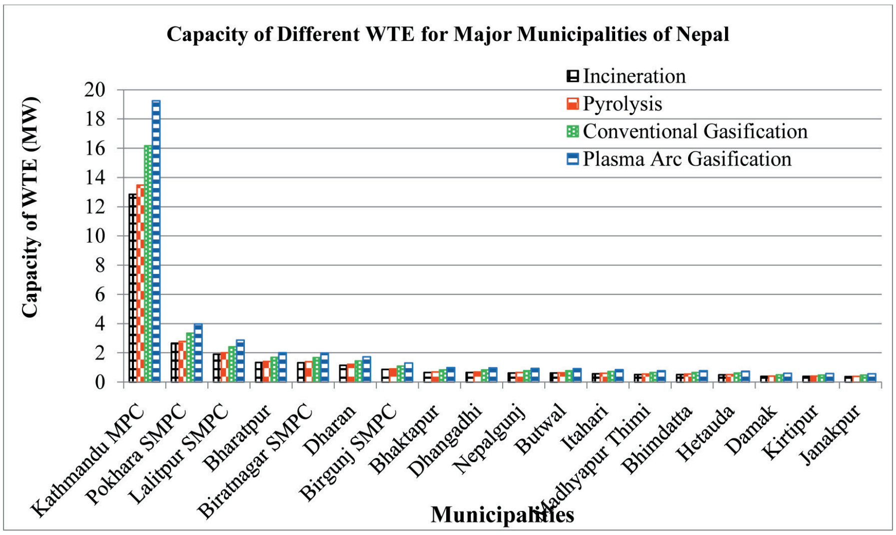

Fig. 8: Capacity of different WTE for major Municipalities of Nepal

4.6 GHG Mitigations

The total GHG emission reduction achievable through the use of waste to energy schemes stands at 220,697 kg CO_2 equivalent per day. Fig. 9 shows the plot of the GHG emission reduction of major municipalities of Nepal. Kathmandu has the highest potential at 87,555 kg CO_2 equivalent per day followed by Lalitpur at 15,357 kg CO_2 equivalent per day and Pokhara at 14,428kg CO_2 equivalent per day.

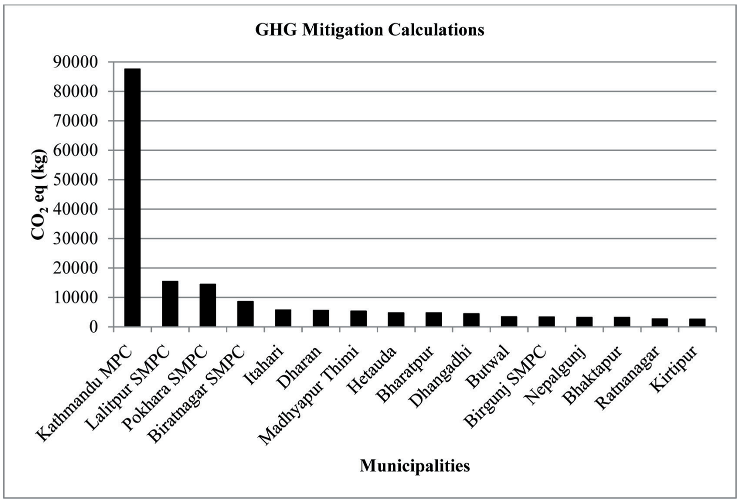

Fig. 9: GHG mitigation of MSW

4.7 Levelized Cost

The levelized cost of electricity (LCOE), also known as Levelized Energy Cost (LEC), is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. Considering above mentioned capital cost, service life, operation maintenance cost, depreciation, escalation rate and discount rate the levelized cost of energy for plasma technology was found NRs. 8.5 per KWh. Similarly levelized cost of energy for gasification technology, pyrolysis technology and incineration technology was found NRs. 9.5, NRs. 11, and NRs. 12.5 per KWh respectively.

5. Conclusion

The total waste generated by the municipalities of Nepal is 1,435 tons per day with per capita waste generation of 0.32 kg, which is consistent with other major cities in Nepal. Total industrial waste production was found to be 65 tons/day, commercial waste was found to be 447 tons/day, and similarly household waste production was found to be 769 tons/day. The total energy potential of the considered municipalities of Nepal was found to be 4260 MWh. This translates to a power plant of 35 MW. For Kathmandu, the total energy potential was found to be 1745 MWh which translates to 14 MW electricity plant. Similarly the total energy potential of Lalitpur and Pokhara were found to 2.3 MW and 2 MW respectively. The total GHG emission reduction achievable with the implementation of waste to energy plant was estimated to be 220,690 kg CO_2 equivalent per day. For Kathmandu this reduction potential stood at 87,555 kg CO_2 equivalent per day followed by Lalitpur at 15,357 kg CO_2 equivalent per day. Incineration can power 34 MW plant combined nationwide. Pyrolysis can power 36 MW plant combined nationwide. Conventional Gasification can power 43 MW plant and plasma arc technology can power plant 52 MW. Of the various technologies available for waste to energy, it was found that although with high investment cost, plasma arc technology has the lowest payback period and also financially effective followed by pyrolysis, gasification and incineration respectively.

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