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ORIGINAL CONTRIBUTION

Municipal Solid Waste Management and its Energy Potential in Roorkee City, Uttarakhand, India

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Abstract Energy plays a vital role in the development of any country. With rapid economic growth and multifold urbanization, India faces the problem of municipal solid waste management and disposal. This problem can be mitigate through adoption of environment friendly technologies for treatment and processing of waste before it is disposed off. Currently, urban and industrial wastes throughout India receive partial treatment before its final disposal, except in few exceptional cases. This practice leads to severe environmental pollution problems including major threat to human health. There is an absolute need to provide adequate waste collection and treatment before its disposal. Municipal Solid Waste (MSW) is getting importance in recent years. The MSW management involves collection, transportation, handling and conversion to energy by biological and thermal routes. Based on the energy potential available, the energy conversion through biogas production using available waste is being carried out. Waste-to-energy is now a clean, renewable, sustainable source of energy. The estimation of energy content of MSW in Roorkee city is discussed in this paper. Furthermore this paper also takes into account the benefits of carbon credits.

Keywords Municipal solid waste · Waste managements · Carbon credit · Power generation · Waste-to-energy

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Introduction

An exponentially increasing population, rapid urbanization and worldwide industrialization in developing Asian countries has led to migration of people from villages to cities, which generate thousand tonnes of MSW daily. The MSW amount is expected to increase significantly in the near future as the country strives to attain an industrialized nation status by the year 2020 [1]. More than 90 % of the MSW generated in India is directly disposed on land in an unsatisfactory manner [2]. MSWM is the major problem being faced by municipalities because it involves a huge expenditure and receives scant attention [3]. More than 2920 TPD of solid waste is generated in Kolkata Municipal Corporation area and around Rs. 1590 million have been allocated for MSWM in 2007–2008. This expenditure remains in sufficient for providing adequate MSWM services [4]. Poor collection and inadequate transportation are responsible for accumulation of MSW at every nook and corner. MSWM, like most of other infrastructural services has come under great stress, consider low priority areas, solid waste management was never taken up seriously either by public or by concerned agency or authorities and now the piled up waste is threatening our heath, environment and well being [5]. Jain and Sharma has presented the results of physical, proximate and TGA/DTA analysis, to select the most appropriate energy conversion method along with the cost benefits analysis with CDM projects. The key issues involved in the solid waste management are growth in population, increasing garbage generation, waste collection system, segregation of waste at source in as many categories as practical, scientific processing of waste material depending on nature.

Government Policy for MSWM

In September 2000, India framed its first Municipal Solid Waste Rules [6], which lets both cities and their citizens know their duties and responsibilities for hygienic waste management. They are based on the March 1999 Report of a Committee for Solid Waste Management in Class 1 Cities of India to the Supreme Court, which urged statutory bodies to comply with the Report's suggestions and recommendations. These rules are based on the principle that the best way to keep streets clean is not to dirty them, summarized below,

- Identification of landfill sites for long-term future use and making them ready for operation, setting up of waste-processing and disposal facilities and provision of a buffer zone around such sites. Biodegradable wastes should be processed by composting, vermin composting etc. and landfilling shall be restricted to non-biodegradable inert waste and compost rejects.
- The Rules also require municipalities to ensure community participation in waste segregation (by not mixing "wet" food wastes with "dry" recyclables like paper, plastics, glass, metal etc.) and to promote recycling or reuse of segregated materials. Garbage and dry leaves should never be burnt. Biomedical wastes and industrial wastes must not be mixed with municipal wastes.
- The Report recommends that cities should provide free waste collection for all slums and public areas, but charge the full cost of collection on "Polluter-Pays". Principle, from hotels, eateries, marriage halls, hospitals & clinics, wholesale markets, shops in commercial streets, office complexes, cattle-sheds, slaughter-houses, fairs & exhibitions, inner-city cottage industry & petty trade.
- Debris and construction waste must be stored within premises, not on the road or footpath, and disposed of at pre-designated sites or landfills by builder, on payment of full transport cost if removed by the Municipality.
- For improved work accountability, "pin-point" work assignments and 365-day cleaning are recommended, with fixed beats for individual sweepers, including the cleaning of adjoining drains less than 2 ft deep. Drain silt should not be left on the road for drying, but loaded directly into hand-carts and taken to a transfer point. Silt and debris should not be dumped at compost—plant.
- The quantities of garbage collected and transported need to be monitored against targets, preferably by citizen monitoring, through effective management information systems and a recording weigh- bridge: computerised for 1 million cities. At least 80 % of waste-clearance vehicles should be on-road, and two-shift use implemented where there is a shortage of vehicles. Decentralised ward—wise composting of well—segregated wet waste in local parks is recommended, for recycling of organics and also for huge savings in garbage transport costs to scarce disposal sites.
- The Report also recommends that waste-management infrastructure should be a strictly-enforced pre-condition in new development areas. It advocates temporary toilets at all construction sites (located on the eventual sewage-disposal line) and restriction of cattle movement on streets. Livestock should be stall-fed or relocated outside large cities.

Indian Scenario

Solid waste management has become a major environmental issue in India. The per capita MSW generated daily, in India ranges from about 100 gm in small towns to 500 gm in large towns. Although, there is no national level data for MSW generation, collection and disposal, and increase in solid waste generation, over the years. Growth in MSW in our urban centres has outpaced the population growth in recent years. This trend can be ascribed to our changing lifestyles, food habits, and change in living standards. MSW in cities is collected by respective municipalities and transported to designated disposal sites, which are normally low lying areas on the outskirts of the city. Substantial part of the MSW generated remains unattended and grows in the heaps at poorly maintained collection centre. The choice of a disposal site also is more a matter of what is available than what is suitable. The average collection efficiency for MSW in Indian cities is about 72.5 % and around 70 % of the cities lack adequate waste transport capacities [7]. The waste generated, population, quantity of waste generated per day and per capita by different cities of India is shown (Table 1).

About Roorkee City

Roorkee is a small town located in the foothills of Himalayas in the beautiful state of Uttrakhand in north India as shown in Fig. 1. It is a part of the district and holy city of Haridwar which is merely 30 km distance away. It is about 175 KM north of the Indian capital, New Delhi and located between the rivers Ganga and Yamuna on the banks of the upper Ganga Canal, which take off at Haridwar, Roorkee city is situated at 29°52′N latitude and 77°53′E longitude. Roorkee is the gateway to pilgrim centres of Haridwar, Rishikesh, Badrinath and Kedarnath. It is situated on National highway NH-58 (Delhi-Haridwar) as-well-as on NH-73 (Haridwar-Panchkula).

Table 1 MSW generated by different cities [8]

Name of city	Population (as per 2001 census)	MSW, tonne/day	MSW/ Capita/day
Kavaratti	10,119	3	0.3
Gangtok	29,354	13	0.44
Itanagar	35,022	12	0.34
Daman	35,770	15	0.42
Silvasa	50,463	16	0.32
Panjim	59,066	32	0.54
Kohima	77,030	13	0.17
Port Blair	99,066	76	0.76
Shillong	132,867	45	0.34
Shima	142,555	39	0.27
Agartala	189,998	77	0.4
Gandhinagar	195,985	44	0.22
Dhanbad	199,258	77	0.39
Pondicherry	220,865	130	0.59
Imphal	221,492	43	0.19
Aizwal	228,280	57	0.25
Jammu	369,959	215	0.58
Dehradun	426,674	131	0.31
Asansol	475,739	204	0.44
Kochi	595,575	400	0.67
Raipur	605,747	184	0.3
Bhubaneshwer	648,032	234	0.36
Thiruvanantapuram	744,983	171	0.23
Chandigarh	808,515	326	0.4
Guwahati	809,895	166	0.2
Ranchi	847,093	208	0.25
Vijayawada	851,282	374	0.44
Srinagar	898,440	428	0.48
Nmaduri	928,868	275	0.3
Coimbatore	930,882	530	0.57
Jabalpur	932,484	216	0.23
Amritsar	966,862	438	0.45
Rajkot	967,476	207	0.21
Allahabad	975,393	509	0.52
Visakhapatnam	982,904	584	0.59
Faridabad	1055,938	448	0.42
Meerut	1068,772	490	0.46
Nashik	1,077,236	200	0.19
Varanasi	1,091,772	425	0.39
Jamshedpur	1,104,713	338	0.31
Agra	1,275,135	654	0.51
Vadodra	1,306,227	357	0.27
Patna	1,366,444	511	0.37
Ludhiana	1,398,467	735	0.53
Bhopal	1,437,354	574	0.4
Indore	1,474,354	557	0.38
Nagpur	2,052,066	504	0.25
Lucknow	2,185,927	475	0.22
Jaipur	2,322,575	904	0.39
Surat	2,433,835	1000	0.41
Pune	2,538,473	1175	0.46
Kanpur	2,551,337	1100	0.43
Ahmedabad	3,520,085	1302	0.37
Hydrabad	3,843,585	2187	0.57
Bangalore	4,302,326	1669	0.39
Cheenai	4,343,645	3036	0.62
Kolkatta	4,572,876	2653	0.58
Delhi	10,306,452	5922	0.57
Mumbai	11,978,450	5320	0.45

MSW Generated in Roorkee City

The population of Roorkee city as per the census 2011 is 2,52,784. Total waste generation per day is around 84 tonne per day per Nagar Palika Parisadh Roorkee (NPPR). The per capita generation is around 0.33 kg/day. NPPR is responsible for the management of the MSW generated in the city. Generation of MSW for different cities have been listed in Table 1.

MSWM in Roorkee City

In Roorkee, generation of MSW has been increasing due to population growth, life style changes and economic development. On the other hand, waste management responses have not kept pace with the increasing quantities of waste resulting in a high proportion of uncollected waste, poor standards of transportation, storage, treatment and disposal. The insanitary methods adopted for disposal of solid wastes is a serious health concern with significant environmental, social and health costs associated with it. Open dumping of garbage facilitates the breeding of disease vectors such as flies, mosquitoes, cockroaches, rats, and other pests. The poorly maintained landfill sites further, are prone to groundwater contamination because of leachate production. Figure 1 shows the schematic of Roorkee city.

Sources and Quantity of MSW in Roorkee City

The major sources of MSW generation of the city are domestic, shops and commercial establishments, hotels, restaurants, hospitals, institutions, meat market, fruit and

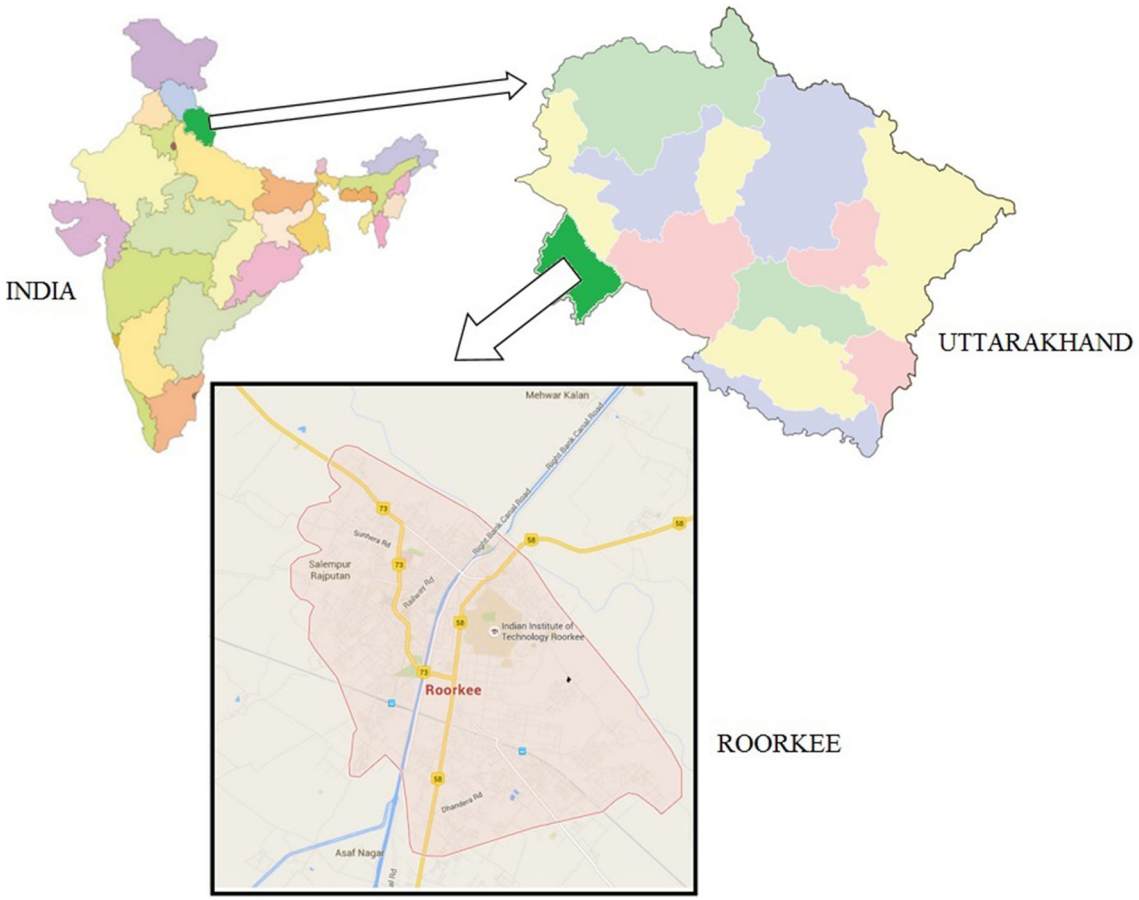

Fig. 1 Map of Roorkee City

vegetable markets. There are three fruit and vegetable markets. Number of hotels and restaurants in the city are 27 and 63 respectively. In addition there is one meat market (Courtesy-NPPR). Quantities of waste generated from various sources are presented (Fig. 2).

Collection and Storage

Mostly localities in city except few localities called Mohalla, having no primary collection system. In these areas, Mohalla Swachhata Samities (MSS) recently started door to door primary collection by engaging private sweepers. Waste is mostly collected through community bins/containers and road sweeping. Sweepers collected waste into small heaps and subsequently loaded manually or mechanically on to the community containers/bins or directly loaded on to the solid waste transport vehicle. But other area of city like IIT Roorkee and other prime organizations are equipped with depot for storage of MSW, which are scattered in these area. The depots are an open space enclosed on three sides with a masonry wall and fourth side partially opened of about 1 m height, with capacities of 1.875 m^3 (Fig. 3). NPPR has also provided two types of community bin containers for MSW storage. The first one has placed on small pole with its capacity is 54×10^{-3} m^3. The bin is placed along the roadside. The second type of community bin has wheels with capacity of 1.5 m^3 (Fig. 4).

Transport to Dumping Site

In Roorkee city the dumping site ranges within 5 km of the collection points, NPPR vehicles directly transport the MSW from storage point to dumping site. NPPR vehicles collect MSW from various community bins/container, heaps and depot. NPPR presently utilizes the following vehicles and equipment for transportation of solid waste (Table 2). Tractor trolley has been shown in Fig. 5.

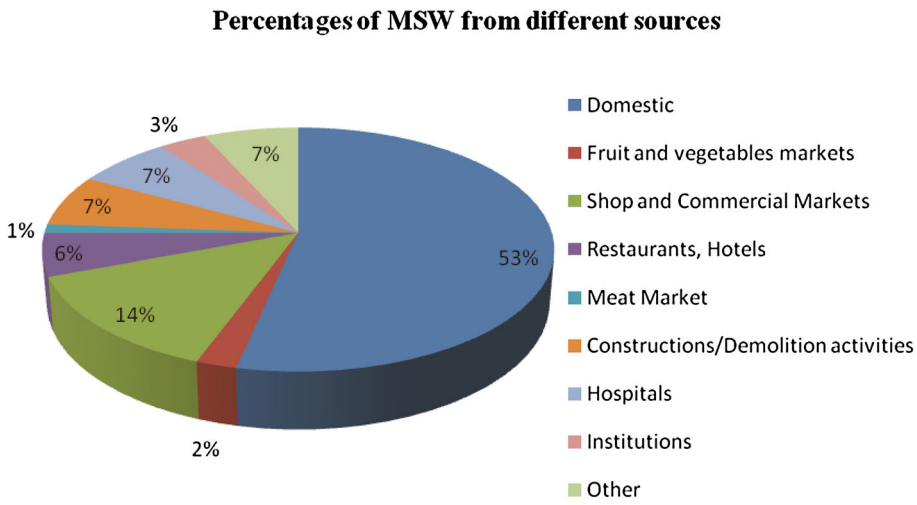

Fig. 2 MSW generated from different sources (NPPR)

Fig. 3 Depot with masonry wall

Fig. 4 Community bin with wheel

Dumping Site of Roorkee

NPPR disposes the MSW of the city to only one site located at national highway-58 at a distance of about 3 km from the city. Area of dumping site is around 0.25 km^2, which is shown in Fig. 1. NPPR disposes the MSW at both side of NH-58. During the visit it was observed that the waste disposal is done by uncontrolled dumping.

Energy Potential of MSW

MSW contains organic as well as in-organic matter. The latent energy present in its organic fraction can be recovered for gainful utilisation through adoption of suitable waste processing and treatment technologies. The recovery of energy from wastes also offers a few additional benefits as follows:

1. The total quantity of waste gets reduced by nearly 60 % to over 90 %, depending upon the waste composition and the adopted technology;
2. Demand for land, which is already scarce in cities, for landfilling is reduced;
3. The cost of transportation of waste to far-away landfill sites also gets reduced proportionately; and
4. Net reduction in environmental pollution.

Figures 5 and 6 show the waste damping places in Roorkee City.

Sampling of MSW of Roorkee

Total 8 samples collected from different location of dumping site. The sample collected from dumping at 1 feet above the earth surface. Out of 8 samples 4 samples collected from recently unloaded truck. Each sample had 1 kg

Table 2 Vehicle presently utilized by NPPR for transportation of MSW

S. No.	Vehicle type	Quantity
1	Tractor trolley	5
2	Container carrier tractor	3
3	Mechanical loader	2
4	Rickshaw	18

Fig. 5 Municipal vehicles loading with MSW

Fig. 6 Dumping site of Roorkee City

of MSW. These samples weighed on each individual component basis and on complete sample basis. These samples dried in sunshine until the moisture is removed and weighed the component on dry basis. In this way, removed moisture is calculated.

Table 3 Different component of biodegradable MSW and non-biodegradable MSW

S. No.	Component
Biodegradable	
1	Yard waste—YW
2	Vegetable and fruit waste—VF
3	Paper waste—PW
4	Cloth waste—CW
5	Other biodegradable—OB
Non-biodegradable	
6	Plastic waste—PW
7	Glass waste—GW
8	Silt/clay/stone waste—SC
9	Metal waste—MW
10	Other non-biodegradable—ON

Composition of MSW

MSW is classified in two categories namely biodegradable and non-biodegradable. Further these categories classified into their respective components as presented (Table 3). Average amount of biodegradable and non biodegradable material is around 52.3 and 34.3 % respectively and the average amount of moisture is around 13.4 % by weight, which is calculated (Table 4) [9, 10].

Energy Content of MSW

Calorific value is the amount of heat generated from combustion of a unit weight of a substance expressed as kJ/kg as presented in Table 5. The calorific value is determined experimentally using Bomb Calorimeter (Fig. 7). Samples are converted into powder with briquetting machine. After converting MSW into briquettes, calorific values are measured in bomb calorimeter. Average calorific values of biodegradable MSW and received MSW are 1,5888, 8017 kJ/kg respectively.

Proximate Analysis as Received Basis

To know the volatile matter, fixed carbon, moisture content and ash content proximate analysis is carried out using ASTM standard method by muffle furnace (Fig. 8). Results of proximate analysis of MSW on received basis are indicated (Table 6.). Average value of moisture, volatile matter, ash and fixed carbon are 20, 26.7, 35.1 and 18.2 % respectively (Table 6).

Table 4 Composition percentage of MSW of Roorkee city

Sample	Biodegradable, %					Non-Biodegradable, %					Moisture, %	Total, %
	YW	VF	PW	CW	ON	PW	GW	SC	MW	ON		
1	17.2	16.3	11.7	1.1	2.0	3.9	1.3	24	6.2	2.5	13.8	100
2	20.3	14.3	14.3	1.3	1.5	2.1	1.6	21.1	5.2	3.1	15.2	100
3	25.4	12.3	12.5	3.2	2.5	1.6	2.3	11.9	3.2	3.4	21.7	100
4	21.0	14.5	13.0	1.2	2.1	3.2	3.1	24.2	3.4	2.8	11.5	100
5	25.5	16.7	10.2	2.1	1.6	4.1	2.5	18.2	2.6	2.7	13.8	100
6	25.1	18.0	8.1	3.0	1.4	3.7	1.1	24.1	2.1	2.4	11.0	100
7	18.1	21.2	7.2	1.1	0.5	4.2	2.1	30.1	1.3	2.1	12.1	100
8	15.2	22.9	10.0	2.2	0.7	5	1.9	29.9	2.3	1.6	8.3	100

Table 5 Calorific value of received MSW and biodegradable MSW on dry basis

S. No.	Sample	Calorific values of biodegradable materiel in MSW only, kJ/kg	Calorific values of whole MSW, kJ/kg
1	1	15,320	8635
2	2	15,863	8369
3	3	14,853	6542
4	4	17,965	10,236
5	5	14,326	6253
6	6	16,560	9842
7	7	16,850	7362
8	8	15,369	6895
		Average 1,5888	Average 8017

Energy Potential of MSW for Roorkee City

As per component of MSW of Roorkee City

$$\text{Total biodegradable MSW generated per day} = 52.3 \times 84/100 = 43.9 \text{ tonne}$$

$$\text{Power Generation potential} = 15,888 \times 43.9 \times 1000/86400 = 8072.7 \text{ KW}$$

By the above value it can be predicted that energy potential of MSW of Roorkee City is 8 MW. For higher capacity plant MSW collection can be planned from nearby villages of corporation.

Result and Analysis

It has been observed that the average amount of biodegradable and non biodegradable material is around 52.3 and 34.3 % respectively and the average amount of moisture is around 13.4 % by weight. Average calorific values of biodegradable MSW and received MSW are 1,5888, 8017 kJ/kg respectively.

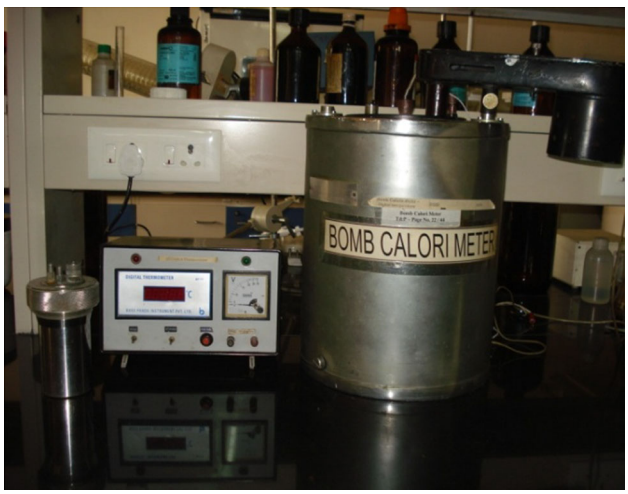

Fig. 7 Bomb calorimeter

Emission of CO_2 from MSW of Roorkee City

As per chemical composition of MSW of Roorkee City the bio gas generated per tonne of MSW = 140 m^3

CO_2 generated by burning of 1 m^3 of biogas = 1.08 kg

Total bio gas generated per day = 6150 m^3

Total amount of CO_2 generated by burning of total MSW per year = 1993 tonne [plant runs 300 days in a year]

The data is given by SKG Sangha, a leading manufacturing company of bio gas plant of India.

Emission of CO_2 from Conventional (Thermal) Power Plant

Amount of CO_2 liberated per KWh = 0.71 kg [11, 12]

Amount of CO_2 liberated per day = 136.32 tonne

Total amount of CO_2 liberated per year = 40,896 tonne

Fig. 8 Muffle Furnace

Table 6 Results of proximate analysis as received basis

S. No.	Sample	Moisture, %	Volatile matter, %	Ash, %	Fixed carbon, %
1	1	23.5	17.6	42.3	16.6
2	2	18.3	24.6	29.3	27.8
3	3	19.6	28.6	42.3	9.5
4	4	26.4	25.6	36.3	11.7
5	5	17.5	23.4	37.5	21.6
6	6	22.3	29.3	29.8	18.6
7	7	17.9	31.2	35.3	15.6
8	8	14.2	33.2	28.3	24.3
		Average 20	Average 26.7	Average 35.1	Average 18.2

Table 7 Comparison and saving of liberated CO_2 by various techniques

S. No.	Technique	Emission of CO_2 per year
1	Conventional (thermal) power plant	40,896 tonne
2	Biogas from MSW	1993 tonne
3	Equivalent saving of CO_2	38,903 tonne

Equivalent Carbon Credits

Cutting global emissions which lead to climate change is playing a vital role in present era. The market for carbon credits is undoubtedly growing rapidly and is already helping to drive a shift away from fossil fuel energy sources towards various renewable energy options and a low carbon economy. This analysis indicates that there is potential for minimizing emission of CO_2 by switching to less carbon intensive techniques. The above discussion highlights the scope of reducing carbon emission and consequences of this reduction in gaining carbon credits. The comparison of emission of CO_2 by various techniques is depicted (Table 7).

According to IPCC norms1tonne of CO_2 is equivalent to \$7.5. Then 38,903 tonne of CO_2 will be equivalent \$291,773, which signifies huge amount of saving by adopting this clean and sustainable technology.

Conclusion

The solid waste management in Roorkee city appears to be inadequate and needs up gradation. Roorkee city might need to look for better solution of waste disposal considering unavailability of landfill and disposal site. The present system of MSW management in Roorkee city is not qualifying the standards as set by MSW Rule 2000. There is need to implement MSW Rule 2000 in an integrated manner. The following conclusions can be drawn from the present study.

- MSW generated per day in Roorkee City is 84 tonnes, which has energy potential of 8 MW.
- Calorific values of biodegradable waste from MSW and received MSW are found to be calculated, which are 1,5888, 8017 kJ/kg respectively.
- The emission of CO_2 from biodegradable MSW is 1993 tonne per year as compare to 40,896 tonne per year for conventional (thermal) power plant of the same capacity.
- By adopting this clean and sustainable technology an equivalent saving of \$ 291,773 may be possible.

This study provides a scope for the planning of energy project in India by mixing urban waste with other wastes of renewable nature like rice husk or bagasse as back-up fuel which is eligible as per national programme on energy recovery from urban waste of the Ministry of New and Renewable Energy (MNRE), Govt. of India.

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