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HARNESSING SOLID WASTE TO ENERGY: A TECHNO-COMMERCIALLY FEASIBLE SOLUTION FOR EFFECTIVE SOLID WASTE MANAGEMENT IN INDIA

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ABSTRACT

Solid waste management (SWM) is a major problem for many urban local bodies (ULBs) in India, where urbanization, industrialization and economic growth have resulted in increased municipal solid waste (MSW) generation per person [1].Solid Waste has been a menace and Solid Waste Management (SWM) is one of the inevitable problems in Indian Cities. Municipal Solid Waste (MSW) generation per capita in India ranges from approximately 0.12 kg per person per day in small towns to approximately 0.62 kg per person per day in cities half of which is biodegradable[2]. Studies in the past reveal that nearly 90 % of the Solid Waste is being disposed in open dumps and landfills without any treatment. The Present study was aimed to comprehend the quantity of Solid Waste generated in India and review the status of SWM. Further, the technologies and best practices to be adopted and replicated for minimizing the pollution due to Solid Waste are discussed along with detailed techno-commercial analyses of biomethanation which is a latest trend in treating biodegradable waste. The solid waste flux a new concept in analyzing the waste load per area of the land is analyzed and is found to be 43.69kg per square kilometer for India.

***KEYWORDS**: Solid Waste, Solid Waste Flux, Waste Generation, Biomethanation*

Article History

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INTRODUCTION

Municipal Solid Waste (MSW) is a complex mixture of food waste, glass, metals, yard trimmings, woody waste materials, non-recyclable paper and plastic, construction and demolition waste, rags, and sludge from waste water treatment. Despite significant development in social, economic and environmental areas, SWM systems in India have remained relatively unchanged. The informal sector has a keyrolein extracting value from waste, with approximately 90 % of residual waste currently dumped rather than properly land filled [3]. MSW presents numerous challenges when used as a feedstock for energy production, it has low energy content, high moisture, heterogeneous composition, it is highly distributed making it difficult for traditional approaches to reach economies of scale [4].When MSW is disposed of in landfills, it generates biogas, which is mostly comprised of methane and carbon dioxide. When captured, this gas can be converted to power, heat, and/or other products [5].India being a developing economy with emphasis on increasing the rate of growth has compromised the environmental front to economic growth. The drastic increase in population has compounded the existing problem of Solid Waste Management. The total quantity of Solid Waste being generated is exceeding the quantity that can be managed with existing infrastructural facilities, many of which are archaic and need to be transformed to contemporary best practices. Improper disposal of Solid Waste will be detrimental to the environment. Further, availability of space for the landfills is limited and disposal is the least prioritized option currently, however there are large numbers of technologies available for effective treatment of waste. Waste needs to be considered as a resource and Waste to Energy (WtE) and Waste to Compost (WtC) are the two transformations which are currently being adopted in several Urban Local Bodies across the globe. In order to understand the exact problem, it is essential to know several aspects of solid waste and the following sections deal with the brief technical information on Solid Waste. MSW poses several key feedstock challenges relative to other biomass streams, which result in increased costs and impair economic viability. Relatively ow energy content: While the composition of MSW varies geographically and seasonally, the energy density is low—approximately 10-13 MMBTU/ton [6,7]—well below sub-bituminous coal at roughly 17-21 MMBTU/ton [7-11].High moisture content: Significant portions of MSW feed stocks are comprised of >75 percent water. Technologies that rely on the application of heat for conversion to either electricity or fuels are inherently disadvantaged as a high amount of energy is expended in heating or drying steps (i.e., evaporating the water beforehand). Energy intensive processes result in energy returns on investment and techno-economics that are unattractive because they require too much energy input[12].Diverse elemental composition: Levels of nitrogen, sulfur, and ash species in MSW are well above those observed for other lingo-cellulosic feedstocks, and create criteria pollutants (e.g., oxides of nitrogen and sulfur) when combusted. For some fractions of MSW (e.g., yard waste and food waste), concentrations of nitrogen and sulfur can be up to 20 times higher than other lingo-cellulosic feedstocks such as corn Stover and pine[13]Additionally, the inorganic fraction of MSW tends to include chlorine, which can produce dioxins when combusted [14]. Technologies that are sensitive to these species and thus require intermediate clean-up and separation steps present techno-economic challenges for MSW feed stocks. The compositional variability is compounded, given that these waste streams (e.g., food waste, non-recyclable paper, and yard waste) are almost always comingled and individual municipalities can have significantly different waste sorting processes. There is an urgent need to move to more sustainable SWM, and this requires new management systems and waste management facilities. Current SWM systems are in efficient, with waste having a negative impact on public health, the environment and the economy [15].

Solid Waste: The Definition

The term "solid waste" means any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities [16].

Classification of Solid Waste

The solid waste is broadly classified in to several types on the basis of source such as (i) Domestic/Residential Waste, (ii) Municipal Waste, (iii) Commercial Waste, (iv) Institutional Waste, (v) Garbage, (vi) Rubbish, (vii) Ashes, (viii) Bulky Wastes, (ix) Street Sweeping, (x) Dead Animals, (xi) Construction and Demolition Wastes, (xii) Industrial Wastes, (xiii)

Hazardous Wastes and (xiv) Sewage Wastes. [17].All the wastes listed above except Industrial Wastes, Hazardous Wastes and Sewage Wastes are termed as 'Municipal Solid Waste'.

Factors Affecting the Generation of Solid Waste

There exist several factors which affect solid waste generation such as Population, Socio-economic status of the cities, Educational level, attitude, behavior of the people and Status of local & national government policies on waste collection and management.

Solid Waste Generation in India- Demographics

The Solid Waste Generation depends on several factors as listed in section 1.3; however, in Indian Context the most important factor is population as India is the second most populous country in the world. The solid waste generated varies in unison with the population. Further, the waste generated is higher in case of cities and lower in case of rural areas. Figure 1 provides data on MSW generation in different states of India. Table 1 shows the demographics of India. Waste generation rate depends on factors such as population density, economic status, level of commercial activity, culture and city/region.

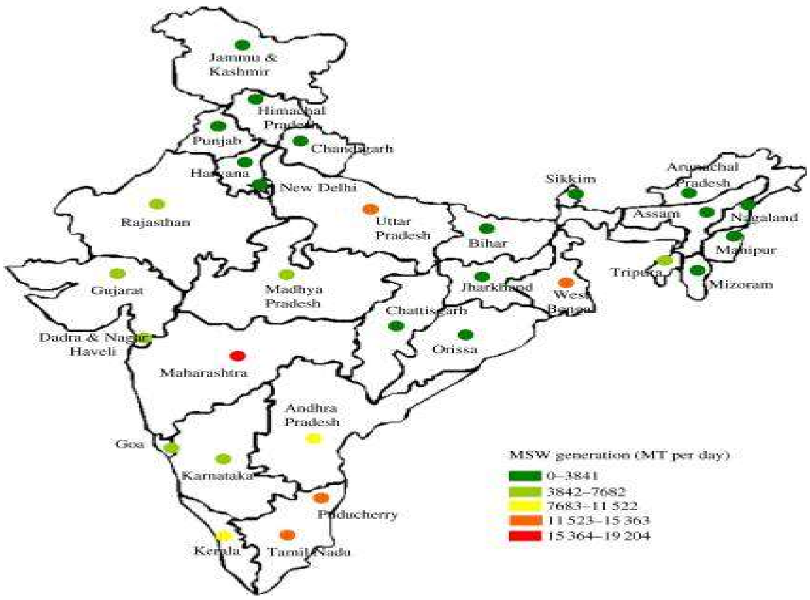

Figure 1: State-Level Statistics of MSW Generation in India (2009–2012). Source: Central Pollution Control Board, Govt. of India, 2012. [1]

Table 1: Brief Demographics of India (Source: Census of India 2011, [18]

Total Population in India (in Millions)	1,210.20
Total Area (Sq.km)	3,287,240.00
Population Density (in Persons/ Sq.km)	382.00
Urban Population (in Millions)	377.10
Rural Population (in Millions)	833.10

Quantification of Solid Waste

As per Central Pollution Control Board (CPCB, 2014-15), 1, 43,449 TPD of MSW was generated for 34 states and union territories during 2013–2014. The average rate of waste generation in India, based on this data, is *0.12 kg/capita/ day*. Out of the total waste generated, approximately 1, 17,644 TPD (82 %) of MSW was collected and 32,871 TPD (22.9 %) was processed or treated [17]). However, the quantity of waste generated is an all-time variant depending on the factors listed in section 1.3.

Correlating the data in table 1 and section 2.2, we can arrive at a unique factor for Solid Waste Generated per Square kilometer of the area, which can be termed as Solid Waste Generation Flux or Solid Waste Flux, which can be denoted by ∅, such that, $\emptyset = \frac{Tota\ \ Waste\ Generated}{Total\ Area}$, in India, it is equal to *43.69kg/km²*

Physical Properties and Characteristics of Solid Waste

NEERI's study "Assessment of Status of Municipal Solid Wastes Management in Metro Cities and State Capitals"in 2004–2005 assessed 59 cities (35 metro cities and 24 state capitals). Studies have revealed that waste generation rate varies from 0.12 to 0.60 kg/capita/day. Analysis of physical composition indicates that total compostable matter in the waste is 40 %–60 %, while recyclable fraction is 10 %–25 %. The moisture content in the MSW is 30 %– 60 %, while the C/N ratio is 20–40[17]. The Density of MSW in India varies from 450 to 500kg/m^3 [19].

The past studies reveal that about 50 % of the total waste being generated is biodegradable.

Table 2: Physical Characteristics of Solid Waste [20]

Year	Composition (%)							
	Biodegradables	Paper	Plastic/ Rubber	Metal	Glass	Rags	Other	Inerts
1996	42.21	3.63	0.60	0.49	0.60			45.13
2005	47.43	8.13	9.22	0.50	1.01	4.49	4.02	25.20

Waste generation Rates in Mega Cities of India

Waste generation varies with respect to population of the city and the same is illustrated in Table 3.

Table 3, it can be observed that although total quantity of Solid Waste generated is proportional to population, the per capita waste generation does not follow the same principle and the other factors listed in section 1.3 determine the waste generation per capita per day. MSW generation per capita in India ranges from approximately 0.17 kg per person per day in small towns to approximately 0.62 kg per person per day in cities, as shown in Table 4.

Table 3 Waste Per Capita in Major Cities of India (2010-11) [21]

City	Population (Million)	Total Waste Generated (TPD)	Waste Generation (kg per capita per day)
Ahmadabad	6.3	2300	0.36
Hyderabad	7.7	4200	0.54
Bangalore	8.4	3700	0.44
Chennai	8.6	4500	0.52
Kolkata	14.1	3670	0.26
Delhi	16.3	5800	0.41
Mumbai	18.4	6500	0.35

Table 4: Comparison of Waste Generation Rate With Respect to Population in Cities of India [22, 23]

Population	Waste Generation Rate (Kg Per Capita Per Day)
Cities with population <0.1 Million (8 Cities)	0.17 -0.54
Cities with population of 0.1 to 0.5 Million (11 Cities)	0.22-0.59
Cities with population > 2 Million (13 Cities)	0.19-0.53
Cities with population of 1 to 2 Million (16 Cities)	0.22-0.62

An Overview of Solid Waste Management in India Functional Elements of Solid Waste Management

The waste Management and Handling Rules in India were introduced by the Ministry of Environment and Forests (MoEF) [24]. In order to assess the waste management practices in India, it is essential to analyze the functional elements of solid waste management effectively. The functional elements have been indicated in Figure 2.

The Figure 2 represents the Solid Waste Management scheme in ideal condition. However, in practice there would be a deviation from ideal state. In the figure,

- Boxes in red shades indicate processes which are detrimental to environment (Waste generation should be minimized at the source, storage of waste for longer periods is not safe, the quantity of waste disposed should be minimized)
- Boxes in green shades indicate ecofriendly practices (Segregation at source make the processing and recovery easier, if the waste is recovered for usable matter, the waste management will be economical and efficient)
- Boxes in blue shades indicate intermittent processes (The collection and transport of waste on regular basis ensures continuity in waste management cycle)

Waste generation and segregation at source lies in the scope of waste generator i.e the general public or citizen; whereas the other aspects are to be carried out by the municipality or the concerned Urban Local Body

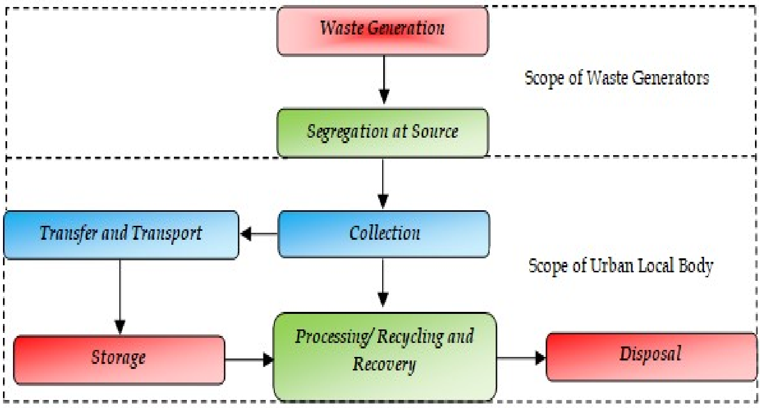

Figure 2: Functional Elements of Solid Waste Management.

Status of Solid Waste Management in India

Currently, the functional elements listed in section 3.1 above, are not being practiced appropriately in India due to lack of awareness, infrastructure and several factors. The status is summarized in Table 5

Table 5: Solid Waste Generation and Management Status in India[24])

S. No	State	All in Tonnes Per Day (TPD)			
		Generated	Collected	Treated	Land Filled
1	Andaman & Nicobar	120.00	117.00	65.10	37.90
2	Andhra Pradesh	6,440.00	6,140.00	548.00	203.00
3	Arunachal Pradesh	270.96	215.00	Nil	Nil
4	Assam	1,293.66	1,119.37	-	-
5	Bihar	2,272.00	Yes	-	No
6	Chandigarh	470.00	458.52	150.00	361.28
7	Chhattisgarh	1,650.00	1,386.00	1,271.00	115.00

Table 5 Contd.,

8	Daman Diu	98.00	94.50	5.00	89.50
9	Delhi	10,817.00	10,614.00	5,714.00	5,225.00
10	Goa	236.41	235.90	154.71	1.49
11	Gujarat	-	11,119.00	1,127.00	9,992.00
12	Haryana	4,635.79	4,430.25	815.93	3,614.32
13	Himachal Pradesh	389.00	340.00	150.00	190.00
14	Jammu & Kashmir	1,530.53	1,452.86	-	-
15	Jharkhand	2,205.00	2,043.40	836.69	0.00
16	Karnataka	11,958.00	10,011.00	4,515.00	
17	Kerala	3,903.02	742.23	437.74	-
18	Nagaland	339.50	216.90	135.80	33.95
19	Lakshadweep	35.00	18.00	18.00	-
20	Madhya Pradesh	8,000.00	7,500.00	6,100.00	1,400.00
21	Maharashtra	23,844.55	23,675.70	12,623.33	11,052.37
22	Manipur	218.60	126.63	80.00	46.63
23	Mizoram	251.42	213.07	29.22	-
24	Meghalaya	170.63	170.63	8.72	161.91
25	Orissa	2,564.43	2,255.32	91.63	2,163.69
26	Punjab	4,634.48	4,574.93	917.56	3,657.37
27	Pondicherry	599.25	505.00	24.00	481.00
28	Rajasthan	6,625.56	6,475.39	780.18	4,187.16
29	Sikkim	75.10	67.10	13.05	51.40
30	Tamil Nadu	13,968.00	12,850.00	7,196.00	5,654.00
31	Telangana	8,497.00	8,360.00	5,747.00	869.00
32	Tripura	445.72	389.46	150.10	239.36
33	Uttarakhand	1,527.46	1,437.40	524.00	-
34	Uttar Pradesh	17,377.30	17,329.40	4,615.00	0.00
35	West Bengal	14,613.30	13,064.63	916.00	334.00
Total		**152,076.70**	**149,748.60**	**55,759.60**	**50,161.33**

Feasible Solution to Manage Biodegradable Waste- Data Analysis

The data studied and obtained from various sources cited in previous sections are hereby summarized to find a feasible solution to manage solid waste.

Table 6 shows indicate that nearly 75,000 Tonnes of biodegradable waste is being generated in India; however, this waste is not being harnessed for energy in majority of the ULBs. Biodegradable waste can be processed to generate biogas and manure.

Table 6: Summarization of Waste Generated in India

Total Quantity of Waste Generated (TPD)	150,000.00
Max. fraction of waste (%)	Biodegradable Waste, up to 50 %
Quantity of Biodegradable Waste (TPD)	75,000.00

Biomethanation of Biodegradable Waste

Biomethanation is a well-studied and practiced process for conversion of organic/biodegradable waste to energy. Biomethanation, also called anaerobic digestion occurs in absence of air with three phases i.e Hydrolysis of organic solids, acetic acid Formation and biogas Production, thereby breaking down the complex organic matter to yield biogas and slurry. Biogas is a mixture of methane, carbon dioxide, hydrogen sulphide, water and other compounds in traces. The digested material obtained in the form of slurry is organic manure to plants [25].The typical composition of biogas is indicated in Table 7

- India being a tropical country is blessed with optimal climatic conditions for biomethanation. Further lot of biogas plants have been successfully commissioned by various agencies throughout India at various scales.
- Biogas is a potential replacement for LPG which is a conventional, exhaustible source of energy and India imports nearly 85 % of the petroleum from foreign Countries.
- Biomethanation is a simple and safe process which eliminates pathogens from the waste.

Considering the above factors, biomethantion technology is feasible for SWM in India.

Table 7: Typical Composition of Biogas [25]

Sl No	Constituent	Percentage
1	Methane	49
2	Carbon dioxide	45
3	Traces [H_2S, NH_3 H_2O, N, H and O]	6

Techno-Commercial Analyses of Biogas Plants

Biomethanation of waste is accomplished through a system known as biogas plant or a bioreactor. A typical biogas plant will be comprised of digester, gas holder, mixer, intermittent flow chambers and biogas pipeline system. Numerous empirical studies and research in India and abroad carried out by various agencies have yielded the following results in general.

- One tonne (1000kg) of biodegradable waste yields nearly fifty cubic metres ($50m^3$). of biogas per day depending on various factors like temperature in the reactor, pH, C/N Ratio of the waste being fed and other factors.
- One cubic meter ($1m^3$) of biogas is equivalent to four hundred grams (0.4kg) of LPG in accordance with the ratio of calorific value of biogas to that of LPG.
- One tonne (1000kg) of biodegradable waste generates nearly 100kg of manure as by product.
- The biogas plant of capacity 1tonne per day in India costs Rs.1.5 Million

Considering the above parameters, the economics of biogas plant to manage 75,000 Tonnes of waste in India is summarized in Table 8.

Table 8: Commercial Analysis of Biogas Plant as a Solution to Manage Biodegradable Waste in India

Parameters	Daily	Yearly
Total quantity of Waste (in TPD) that be managed through biogas plants	75,000.00	27,375,000.00
Biogas generated (Cubic metre)	3,750,000.00	1,368,750,000.00
Biogas equivalent of LPG (kg)	1,500,000.00	547,500,000.00
Savings through LPG per day (Rs. in Million)*(a)	134.34	49,034.10
Manure generation (in TPD)*(b)	7500.00	2,737,500.00
Savings through manure (Rs. in Million)	22.50	8,212.50
Total savings through biogas and manure (Rs. in Million)	156.84	57,246.60
Investment (Rs. in Million)	112,500.00	

*The cost of LPG is considered as Rs.89.56/kg as per the prevailing market rates
*(SING) - Nominal cost of Manure is considered as Rs.3/kg

CONCLUSIONS

The results obtained from the study carried out very clearly explains that India being a populous country is facing a huge challenge in managing the solid waste, lot of waste is being landfilled without recovering energy. The Solid Waste generated per capita per day on an average is 0.12 kg and solid waste generation flux is 43.69 kg per Square kilometer. Majority of the waste (to an extent of 50 %) is biodegradable and biomethanation is a feasible to solution to overcome the energy deficit along with managing the waste effectively. The decentralized biogas plants can be implemented across various cities, towns by the respective urban local bodies to economize the process of waste management. The biogas requires monitoring and maintenance on regular basis; the same can be done by the existing man power allocated for waste management.

CONFLICTS OF INTERES

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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