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A Critical Review on Potential of Energy Recovery and Carbon Saving Through Anaerobic Digestion Method in India

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Abstract: The energy demand in India is increasing substantially and the energy supply is not in pace with demand. The recovery of energy from waste material is one of the best methods to tackle the energy crisis. The potential for recovery of energy from urban waste is high in Maharashtra followed by Uttar Pradesh, Tamil Nadu and West Bengal. In this paper, anaerobic digestion method is used to find the potential of energy recovery from the liquid and solid waste in the form of biogas. Thus the production of biogas from industrial and domestic waste is working successfully in small and large scale private projects in India. The potential of energy recovery has been estimated based on the available data. Also the carbon emission from the natural gas production plant is found and compared with the conventional coal based power production methods.
Keyword – Solid waste, Liquid waste, Anaerobic Digestion / Biomethanation, Carbon Emission, Carbon Reduction.

1 Introduction

At present the rate of economic growth electricity has become a basic necessity for the developing and underdeveloped countries. The electricity has produced from various sources like fossil fuel based. The fossil fuel combustion has polluting the environment in the form emitting greenhouse gases that lead to climate change and global warming. In another way the depletion of fossil fuel resources has lead to think alternative fuel in the form of eco-friendly. Thus mankind has to rely on the alternative / renewable energy sources like biomass, hydropower, geothermal energy, wind energy, solar energy, nuclear power etc. On the other hand, suitable waste management strategy is another important aspect of sustainable development [1].

Carbon dioxide, methane, nitrous oxide and F-gases (Fluorinated gases) are important responsible gases for global warming. CO_2 is contributing more amounts in global GHG emission. From the Figure 1, the major quantity CO_2 is emitting from the use of fossil fuel. Due to decay of biomass and deforestation are adding more CO_2 to the atmosphere. Methane gas is contributing 14% on the global GHG emission. This is mainly result from municipal solid waste land fill, anaerobic degradation of industrial and municipal organic waste and agricultural practice. Nitrogen oxide is emitting from combustion of fossil fuel. F- Gases are emitting during a variety of industrial and commercial activities.

Globally India has holding fourth place in the GHG emission (Figure 3). Every year there is an estimated 30 million tones of solid waste and 4400 cubic meters of liquid waste generated in the urban areas of India [2]. The municipal solid waste (MSW) generation range is from 0.25 to 0.66 kg/person/day with an average of 0.45 kg/person /day. In addition large quantities of solid and liquid wastes are generated by industries that will produce the water and air pollution. [2]. In general, the developed countries generate much higher quantities of waste per capita compared to the developing countries.

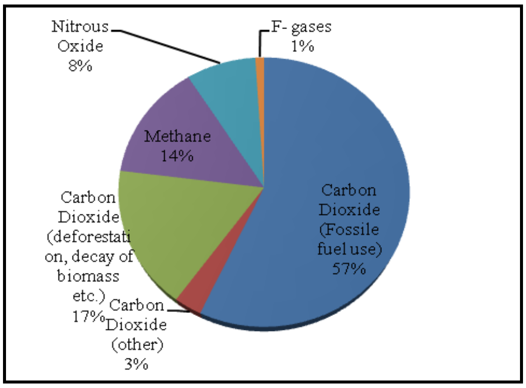

Figure 1Global GHG emission by gas

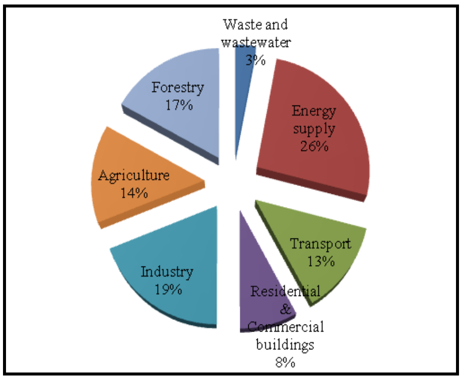

Figure 2 Global greenhouse gas emissions by sources

The problem caused by solid and liquid wastes can be significantly mitigated through the adoption of environment- friendly waste – to – energy technologies that will allow the treatment and the processing of wastes before their disposal. These measures would reduce the quantity of wastes, generate a substantial quantity of energy from them, and greatly reduce the air and water pollution.

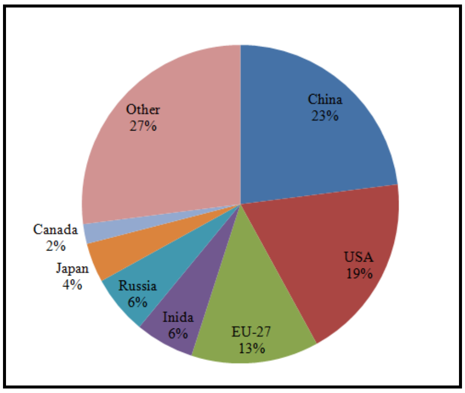

Figure 3 Global GHG Emission by country

1.1India Waste to Energy potential

Waste includes all items that people no longer have any use for, which they either intend to get rid of or have already discarded. Additionally, wastes are such items which people are require discarding because of their hazardous properties. Many items can be considered as waste e.g. household rubbish, sewage sludge, wastes from manufacturing activities, packaging items, discarded cars, old televisions, garden waste, old paint containers etc. Thus all our daily activities can give rise to a large variety of different wastes arising from different sources.

In the Table 1 describe about the potential for energy recovery from the urban liquid and solid waste by state wise. The solid waste generation in the urban waste has more potential to produce the power. Because, the solid waste is contain more amount of biologically degradable organic matter and more volatile components which can be use to produce the power from various methods. Maharashtra is having more potential to produce the power from urban waste followed by Uttar Pradesh, Tamil Nadu, Karnataka and West Bengal leading the potential of power production. The effective utilization of urban waste with appropriate technology can produce the 1683 MW of power [3].

Table 1 Potential for recovery of energy (MW) from urban wastes by state 2011

State/Union Territory	Liquid Wastes (MW)	Solid Wastes (MW)	Total (MW)
Andhra Pradesh	16.0	107.0	123.0
Assam	2.0	6.0	8.0
Bihar	6.0	67.0	73.0
Chandigarh	1.0	5.0	6.0
Chhattisgarh	2.0	22.0	24.0
Delhi	20.0	111.0	131.0
Gujarat	14.0	98.0	112.0
Haryana	6.0	18.0	24.0
Himachal Pradesh	0.5	1.0	1.5
Jharkand	2.0	8.0	10.0
Karnataka	26.0	125.0	151.0
Kerala	4.0	32.0	36.0
Madhya Pradesh	10.0	68.0	78.0
Maharashtra	37.0	250.0	287.0
Manipur	0.5	1.5	2.0
Meghalaya	0.5	1.5	2.0
Mizoram	0.5	1.0	1.5
Orissa	3.0	19.0	22.0
Pondicherry	0.5	2.0	2.5
Punjab	6.0	39.0	45.0
Rajasthan	9.0	53.0	62.0
Tamil Nadu	14.0	137.0	151.0
Tripura	0.5	1.0	1.5
Uttar Pradesh	22.0	154.0	176.0
Uttaranchal	1.0	4.0	5.0
West Bengal	22.0	126.0	148.0
Total	226.0	1457.0	1683.0

The industries are having more potential to produce the power from their waste that is listed out in the Table 2. The potential has estimated based on the characteristic of waste generation and quantities of waste generation. Distillery and sugar industries contain more potential to produce the power from the waste. Industrial waste has contained the potential to produce the power of 1022 MW by various energy producing technologies [3].

Table 2 Potential for recovery of energy from industrial wastes

Sector	**Potential (MW)**
Dairy	49
Distillery	402
Sugar	290
Pulp & Paper	46
Starch	103
Poultry	52
Slaughterhouse	75
Tannery	5
Total	1022

The waste generation per capita is increasing due to population growth and urbanization. Table 5 represent the waste generation per capita for the last 40 years in India and the waste generation in the urban municipal in India.

Table 3 Waste generation per capita in India

Year	Per capita waste generation (g/day)	Total urban municipal waste generation (MT/yr)
1971	375	14.9
1981	430	25.1
1991	460	43.5
1997	490	48.5
2025	700	97

2 Methodology

The following technological options are available for setting up of waste-to-energy projects.

- Anaerobic Digestion/Biomethanation
- Combustion/Incineration
- Landfill Gas Recovery
- Densification/Pelletization

In addition to the above technologies, there are other emerging technologies such as Plasma Arc Technology is being attempted for energy recovery from waste.

The potential of urban waste and industrial waste has been calculated based on the literature review. This study discusses about the feasibility of the anaerobic digestion in the solid waste treatment and waste water treatment. The potential of bio gas generation from the urban waste and selected industrial waste has been estimated.

3 Anaerobic Digestion/ Biomethanation

The anaerobic digestion process is considered to be a minimum of two stage biological reactions, involving at least two different groups of microorganisms, acid-forming bacteria (saprophytic) and the methane forming bacteria. The acid phase is generally considered to include the conversion of complex organic compounds into simpler organic compounds and finally into the organic acids, principally acetic acid by acid-forming bacteria [4 - 8]. The methane formation step is where the major waste stabilization occurs. The stability of the anaerobic process and the rate of gas production are both dependent upon organic loading rates [4,6]. The principal gases produced during the anaerobic digestion process are methane and carbon dioxide. Small amounts of hydrogen sulphide is also produced which may be noticeable in terms of the odour characteristics of the digester gas. Typical details about the biogas are given in Table 4[7].

Table 4 Typical details about biogas

Composition	**55-70%methane, 30-45% carbon dioxide, traces of other gases**
Energy content	6.0-6.5kW/m^3
Fuel equivalent	0.6-0.65 L oil/m^3 biogas
Explosion limits	6-12% biogas in air
Ignition temperature	650-750 ^{0}C
Critical pressure	75-89 bar
Critical temperature	-82.5^{0}C
Normal density	1.2 kg/ m^3
Odour	Bad eggs (the smell of hydrogen sulphide)

The biogas can be used either for cooking/heating applications or for generating motive power or electricity through dual fuel or gas engines, low-pressure gas turbines, or steam turbines. The sludge from anaerobic digestion, after stabilization, can be used as a soil conditioner. It can even be sold as manure depending upon its composition, which is determined mainly by the composition of the input waste.

3.1 Municipal solid waste

Municipal solid waste with the major fractions of paper, cardboard, putrescibles is a potential feedstock for anaerobic digestion [9-13]. Municipal solid waste contains both organic and inorganic fractions. On average the compostable matter percentage is 42.194%, which is a very good amount for anaerobic digestion. The Carbon/Nitrogen ratio which is very important in the conversion process is varying from 21.13 to 30.94 whereas the calorific values are varying from 800.70 to 1009.89 kcal/kg. Studies had been carried on anaerobic digestion of municipal solid waste and it is found that biogas can be generated at a rate of 95m^3/t of solid waste. The biogas potential for the MSW is estimated as 9.23 Mm^3/day [14].

Table 5 survey of municipal solid waste generation and characteristics

Population in range (in million)	No of cities surveyed	Compostable matter	Inert material	Nitrogen as total nitrogen	Phosphorous as P_2O_5	Potassium as K_2O	C/N Ratio	Calorific value (kcal/kg)
0.1 - 0.5	12	44.57	43.59	0.71	0.63	0.83	30.94	1009.89
0.5 - 1.0	15	40.04	48.38	0.66	0.56	0.69	21.13	900.61
1.0 - 2.0	9	38.95	44.73	0.64	0.82	0.72	23.68	980.05
2.0 - 5.0	3	56.57	40.07	0.56	0.69	0.78	22.45	907.18
5.0 and above	4	30.84	53.9	0.56	0.52	0.52	30.11	800.7

3.2 Crop residue and agricultural waste

India being an agrarian country, agriculture is the main source of livelihood for majority of the people. The quantity and quality of biomass obtained from the cultivation of different crops varies significantly. However, there is a lot of biomass available in the form of crop residue and agricultural waste which can be used for anaerobic digestion [15, 16]. The biomass generated is also used as fodder to feed animals, firewood. The remaining biomass may be available for bio energy generation and is estimated as 278.71 Mt/year. The biogas potential for the crop residue and agricultural waste is estimated as 45.8 Mm^3/day [17].

3.3 Wastewater

The wastewater sludge when anaerobically digested can produce biogas [10,13] and the volume of digested sludge is significantly reduced. Anaerobic digestion of sewage sludge has been in practice in India and the biogas obtained is used for different purposes [18]. The data regarding the wastewater generation from the Indian cities is presented in the following Table 6 [19]. The total quantity of wastewater generated is estimated as 15,392 million liters per day (MLD) where as only 10,170 MLD which is about 66% collected through sewerage system and treated conventionally. The wastewater can be converted to biogas using anaerobic digestion.

Table 6 Waste water generation and collection in India

Name of the zone	City Classification	Wastewater generation (MLD)	Wastewater collected (MLD)
South	Very big	669.53	
	Big	58.22	
	Medium	640.42	
	Small	1532	
Total		2900.17	1812
North	Very big	1935	
	Big	394	3932

	Medium	948.26	
	Small	2250	
Total		5527.26	
Western	Very big	978	
	Big	437	
	Medium	780.53	
	Small	1269	
Total		3464.53	2275
Eastern	Very big	55	
	Big	297	
	Medium	631	
	Small	2461	
Total		3444	2151
Total			**10170**

3.4 Animal manure

The total dung production is estimated as 659 Mt annually based on mean annual average dung yield of 4.5kg/day for cattle and 10.2 kg/day for buffalo. The dung produced from cattle and buffalo is estimated as 730 Mt in 2010. The total dung recoverable will be 510 Mt by 2010. Biogas generation from animal manure is not new in India [18, 19]. Anaerobic digestion of the cattle manure has been studied by various people and found to be successful [20 - 22]. The numbers of family size biogas plants which will utilize the dung are estimated to be 12 million by 2010 and produce a biogas of 3448 Mm^3. If the entire dung recovered is used for biogas production, 17,850Mm^3 can be produced by 2010 [14].

3.5 Industrial waste

In this study, major industries which are generating biological waste are considered. The industries include distillery, dairy, pulp and paper, poultry, tannery, slaughter houses; cattle form waste, sugar, maize starch and tapioca starch.

6.5.1 Distilleries

The major process wastewater stream from the distillation stages is the ‘spent wash’ and is regarded as a high strength waste having large potential for generation of biogas using anaerobic digestion[23 - 24] It is estimated that 34,627,395 m^3 of spent wash is produced annually and is available for biogas generation. The total volume of biogas generation potential will be 1,048,393,125 m^3/year [17].

3.5.2 Dairy plants

The dairy industry is having various operations which include silo washing, can and crate washing, plant washing, tanker washing, milk processing, other dairy products, etc. involved in waste production [25, 26]. Here, the base line data is used for calculating the biogas potential from the dairy effluent as per Table 7. The total biogas generation potential of all the 342 dairy units is estimated to be 219,409 m^3/day [17].

6.5.3 Pulp and paper industry

The manufacture of paper generates significant quantities of wastewater; as high as 60m^3/tone of paper produced. The raw wastewaters from paper and board mills are potentially very polluting and observed to be having chemical oxygen demand (COD) as high as 11,000mg/L [27]. There are about 51 agro based mini and medium capacity mills with a total capacity of 2921 tpd (tons per day). The following base line data is used for estimation of biogas from pulp and paper industry waste (Table 7). The total daily biogas generation potential from the anaerobic treatment of black liquor from all these units will be 412,278m^3/day [17].

3.5.4 Slaughter house

The total meat production in the country is 4.42Mt, which includes beef, buffalo meat, mutton, goat meat, pork and poultry meat. [28]. The wastewater from the slaughter house is strong in nature, with a COD to (biological oxygen demand) BOD ratio of 2 to 2.5. Studies have been carried on the slaughter house wastewater

[29, 30]. Biogas potential is estimated based on the base line data as shown in Table 7. The wastewater which is generated from the slaughter house is calculated on the basis quantum of buffaloes and sheep slaughtered and processed and estimated as 533652 m^3/day. The biogas potential of the wastewater from the slaughter house is estimated as 1494225 m^3/day.

3.5.5 Sugar Industries.

Sugar industries generate bagasse as a solid waste and other process wastes include wastewater and press mud. The major process wastewater streams from sugar industries are milling, cooling water, boiler blow down, sulphur house, lime house and spray pond overflow. The wastewater obtained is used for anaerobic digestion and biogas is produced from it [31]. The baseline data for calculating average biogas energy potential for sugar industries is given in Table 7. The total quantum of wastewater generated from 431 sugar factories is up to 534000 m^3/day. 534000 m^3 of biogas can be generated per day from the digestion of wastewater from the sugar industry.

Table 7 Characteristics of effluent from Distillery, Dairy, Pulp & Paper, Slaughter and sugar

Parameter	Distillery	Dairy	Pulp & Paper	Slaughter	Sugar	
					Combined wastewater	Pressmud
Annual operating days	300	350				
Spent wash quantity	15cum/KL					
BOD (mg/l)	45000	2500	4000	3750	1500	
COD (mg/l)	100000	5500	11000	7000	2500	
BOD removal efficiency (%)	80	85	80	85	85	
COD removal efficiency (%)	65	75	60	75	75	
Biogas Methane (%)	60	60	60	60	60	60
Biogas Quantity (cum/cum wastewater)/(m^3/kg of COD removal)	25	0.5	0.5	0.5	0.5	0.8

6.5.6 Poultry

There are three main phases in poultry industry namely production, development, and processing which produces wastes such as egg shells, unhatched eggs, poultry dropping, waste feed etc. [32, 33]. The physical composition of fresh poultry manure is given in Table 8. Biogas potential is estimated based on the following baseline data given in Table 9. The total biogas potential of all the farms in the country is estimated as 438277m^3/day [17].

Table 8 Characteristics of Poultry industry waste

Proximate Analysis		Ultimate Analysis	
Constituents	%	Constituents	%
Moisture	8.2	Carbon	24.84
Volatile Matter	50.3	Hydrogen	1.9
Fixed Carbon	10.2	Sulpher	2.5
Ash	28.8	Nitrogen	2.5
Others	2.5	Oxygen	33.76
Heating Value		2276	

But potential of individual farms is not enough to set up an independent energy recovery unit. The cluster farms can have a combined energy recovery unit.

Table 9 Biogas energy potential of poultry manure

Parameter	Value
Poultry litter generated per bird	100g/bird/day
Moisture content	40%
Volatile solid content	50%
Volatile solids utilized for biogas generation	40%
Biogas produced	0.8m3/kg of volatile solids destroyed

4 Result And Discussion

4.1 Biogas potential in India

The generation of waste in urban and industries has been estimated based on the various case studies. Also the biogas generation has been estimated from the above waste through Anaerobic Digestion/ Biomethanation process and that has been listed out in table 10. Based on the effluent characteristics, distilleries and slaughter house wastes are having more potential to produce the biogas. When comparing the urban waste, the generations of waste water quantities are more respectively the generations of bios gas quantities are also very high. The proper collection system and proper process implementation is required to achieve the above mentioned biogas production.

Table 10 Biogas potential in India

Sources	Biogas potential (m^3/day)
Urban waste	
Solid	923
Liquid	7159680
Crop residue & Agriculture waste	4580
Animal Manure	1785000
Industrial waste water	
Distilleries	2872310
Dairy	219409
Paper and Pulp	412278
Slaughter house	1494225
Sugar	534000
Poultry	438277
Total	**14920682**

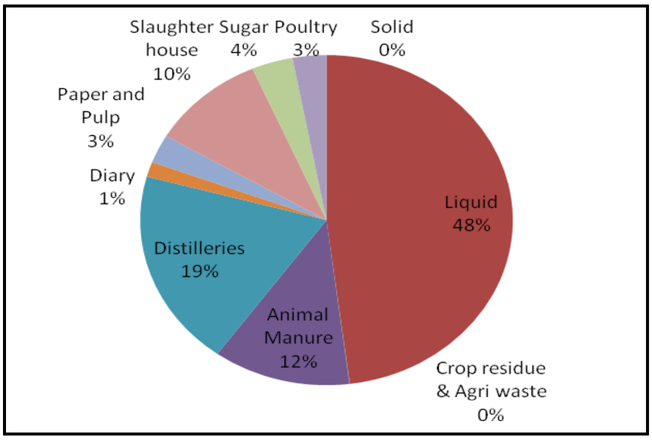

Figure 4 Biogas potential in India

4.2 Energy production from biogas potential in India

The estimated biogas potential can be used to produce the power or any other energy utilization. The assumption has been made from the literature survey like one m^3 of biogas is able to produce the 6kWh of power [9]. Based on that the potential of power production has been estimated. From the table 11, the total potential of power production is 89524 MW/ day. As per the CEA load generation balance report the power shortage in the financial year of 2012-13 is 6.2%. that is equal to 12295MW . The proper utilisation of waste to energy will compensate the above power shortage.

Table 11 Energy production from Biogas potential in India

Sources	Energy Potential (MW/day)
Urban waste	
Solid	6
Liquid	42958
Crop residue & Agriculture waste	27
Animal Manure	10710
Industrials waste water	
Distilleries	17234
Dairy	1316
Paper and Pulp	2474
Slaughter house	8965
Sugar	3204
Poultry	2630
Total	**89524**

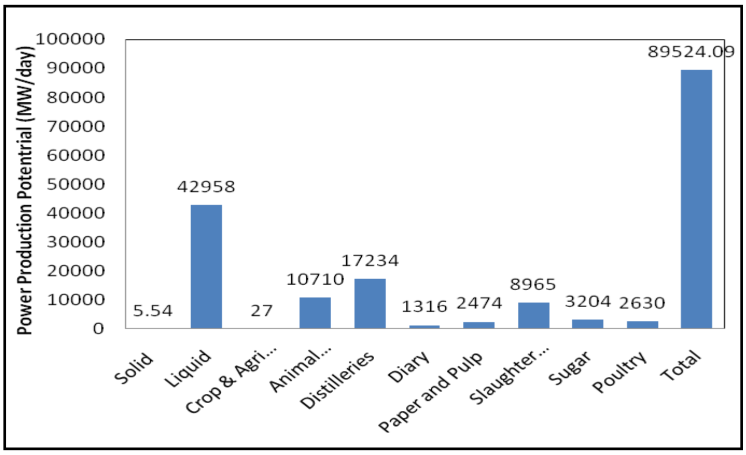

Figure 5 Power production from biogas potential in India

4.3 Comparison of Carbon Emission from Natural gas and Conventional methods

The carbon intensity of coal based power plant and biogas power plant has been compared with each other based on the potential of power production. The effective utilization of biogas from the various wastes can be reduced the carbon emission nearly 4520 tons per day.

Table 12 comparison of CO_2 Emission

Sources	CO_2 Emission Per MW power production (kg)	Potential of power generation (MW/day)	Total CO_2 Emission (kg/day)
Natural gas	469	89524.09	41986798
Coal	974	89524.09	87196464
Carbon Emission Reduced	45209666.7 kg/day of CO_2 is reduced by using natural gas for energy production		

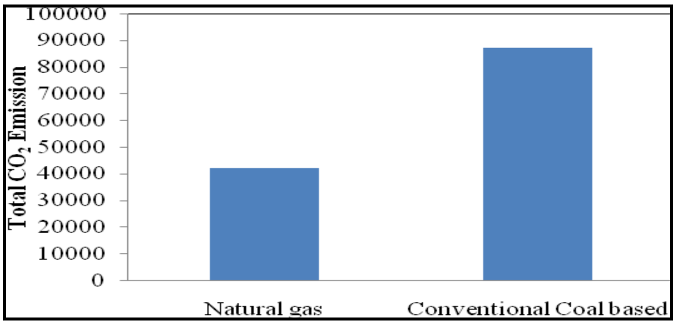

Figure 6 Comparison of carbon emission

5 Conclusion

With increasing demand for energy to maintain a standard of living, many countries now move forward to renewable energy sources. Renewable energy sources are the best alternative however the diversified form leads to a lot of inconvenience in usage. This paper revolves the energy extraction from the waste which is an inventible source of the processing industries. If all the industries adopt these technology, every industry will become self sustain in energy production. As a whole the industries will change from energy intensive to energy generation system which will solve the future energy crisis. The effective utilization of the waste to energy power can reduce significantly the power shortage in India. Also reduce the carbon emission nearly 4520 tons per day.

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