An assessment on “Waste to Energy” potential in Sri Lanka

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Introduction

Garbage is an irritating issue, which causes economic, environmental, social, and health problems to the country. The management of the municipal solid waste is a mandatory responsibility of the relevant Local Authorities (LA). There are 335 LAs in Sri Lanka; 23 Municipal Councils, 41 Urban Councils and 271 Pradeshiya Sabhas. Legislations required for waste management is provided under the Local Government Laws, and the Local Authorities are responsible for the collection and disposal of solid waste in the area of the Authority. The governing legislations related to the three types of Local Authorities i.e. Municipal Councils Ordinance, Urban Councils Ordinance, and Pradheshiya Sabhas Act, have made necessary provisions in relation to the management of waste.

Total waste collection by Local Authorities of Sri Lanka is around 3,700 tons per day out of a total estimated waste generation of more than 6,400 tons per day.

Colombo Municipal Council (CMC) is the key stakeholder which handles the largest waste amounting to 650 ton/day. In view of the economic concerns, the Colombo Municipal Council (CMC) spends around 20% of its annual budget for the management of Municipal Solid Waste (MSW) in Colombo Metropolitan area. The CMC’s budget for collection, transportation and dumping of one torru of MSW is estimated to be about LKR 3,500, total amounting to 2.4 million per day, and is 876 million annually.

In addition to environmental hazards, usually one tonne of biodegradable waste releases 300 liters or 0.4 tone of methane, whose comparative impact on climate change is 25 times greater than CO_2. Another serious environmental impact is ground water pollution, which impose limitations on drinking water in and around garbage dump sites of the country. Sri Lanka Sustainable Energy Authority (SEA) has issued 5 energy permits for the production of around 43.4MW. But so far none of the projects have become a reality yet. The above five projects are located in Muthurajawela, Karadiyana, Kaduwela, Gampaha and Aththanagalla in the neighbourhood of the major dump sites. The two major dump sites at Meethotamulla and Blumendal are now abandoned. In addition, there are about 20 minor dumps sites in the country. Table 01 shows the amount of garbage collection in the country.

Considering the social impact, these garbage dump sites have created many problems such as reducing the land value, and creating an

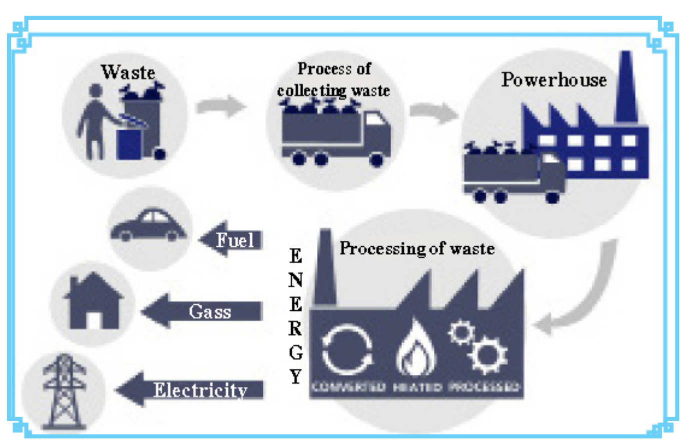

Figure 1 : Process of power generation from waste

unpleasant environment for living with bad odor and attracting many unwanted animals such as dogs, cows, crows and sometimes elephants etc. In addition, liquid and solid waste from households and the community, causes serious health hazard, leading to the spread of infectious diseases. Normally it is the wet waste that decomposes and releases a bad odour and attracting many unwanted animals such as dogs, cows, crows and sometimes elephants etc. In addition, liquid and solid waste from households and the community, causes serious health hazard, leading to the spread of infectious diseases. Normally it is the wet waste that decomposes and releases a bad odour. This leads to unhygienic conditions and thereby to a rise in health problems. Certain chemicals if released untreated, e.g. cyanides, mercury, and polychlorinated biphenyls, are highly toxic, and exposure can lead to disease or death. Some studies have shown alarming number of cancer cases among residents exposed to hazardous waste. The unhygienic use and disposal of plastics and its effects on human health has become a matter of concern. Coloured plastics are harmful as their pigment contains heavy metals that are highly toxic. Some of the harmful metals found in plastics are copper, lead, chromium, cobalt, selenium, and cadmium. In most industrialized countries, coloured plastics have been legally banned. The above mentioned direct and indirect impacts of open dumping of waste has still not been seriously taken into account by anybody. Providing solutions to solid waste management issues will solve the multifaceted dimensions on economic, environmental, social and health hazard, and eliminating this issue can lead to development of the country.

Table 1 : Provincial garbage collection

Province	Number of. Local Authorities				Amount of Daily Collection
	MC	U.C	D.C	Total	
Western	7	14	27	48	1,873
Central	4	6	33	42	319
North Western	1	3	29	32	353
Sabaragamuwa	1	3	25	29	166
Southern	3	4	42	50	227
North Central	1	-	25	26	96
Uwa	2	1	25	27	100
Eastern	3	5	37	44	506
Northern	1	5	28	34	130
Total	23	41	271	335	3740

Further, the institutions which are engaged in waste disposal have still not been able to provide sustainable solutions. In accordance with the provisions in Section 4 of the Sri Lanka Sustainable Energy Authority Act No. 35 of 2007, the Authority is vested with the power to "Identify, Assess and develop renewable Energy Resources with a view to enhancing energy security and thereby derive economic and social benefits to the country." The data available with the Authority as well as mapping of waste quantities carried out in the recent past, has shown that nearly 55% of the collected solid waste in Colombo and suburbs are organic matter which can be considered as a renewable source of energy from which electricity/heat energy/bio gas can be generated. Therefore, there is a necessity to coordinate other respective bodies which are managing waste in the country to jointly develop the effective potential benefits out of waste to the Renewable Sector.

As an initial step, it is necessary to implement a pilot scale waste to energy power plant by the government, so as to provide technical information to the private developers to identify the suitable technology, and come up with the correct plant type efficiency. It is also necessary to fix a feed in tariff for waste to energy projects as well as provide, funding mechanism through grants, loans, incentives etc. or other indirect incentives such as communication campaigns to develop waste energy projects by the private sector.

2.0 MSW composition and waste characteristics

The key technical parameters required for the designing of a waste to energy plant are the composition analysis and the characteristics of raw material. Presently our country as a developing country is burdened with more biodegradable wastes. It is a known fact that with the changing socio-economic status of a country, it is expected that the organic component of municipal solid waste to gradually decrease, while inorganic and combustible fractions to progressively increase. The Gross Domestic Production (GDP) is a factor for measuring the state of development of a country. A MSW characterization had been conducted in 2004 by the Central Environmental Authority which shows that, the per capita GDP was USD 1,035. When a similar analysis was done in 2015, the country's per capita GDP was approximately USD 2,135, indicating the requirement for a new MSW characterization within the Colombo municipality. Therefore, a characterization study has been conducted by Sri Lanka Sustainable Energy Authority in 2015 using an internationally recognized methodology, as such reliable information is needed in aligning waste management activities. Table 02 shows the per capita MSW generation in different regions of the world.

Table 2 : Generation of Waste (MSW/Percapita)

Country and Area		Generation of Waste (Kg / day / person)
Europe		0.70 - 0.85
United Kingdom		1.25 - 1.80
Developing Countries	Low income category	0.25 - 0.6
	Middle income category	0.5 - 0.85

Western Province accounts for more than 50% of the country's daily waste generation. MSW generated in Sri Lanka is dominated by bio degradable material and in Western Province it is around 55%. A Composition analysis of solid waste collected by Colombo Municipal Council is given below.

This analysis revealed that the MSW composition had changed from the previous analysis conducted in 2004. Biodegradable percentage has dropped from 65% to 54% between 2004 and 2015. Polythene and plastics percentages have increased to 13.7% from 5.4%, while paper and cardboard percentage had also increased to 10.2% from 7% during the last decade. The average moisture content of these MSW is 63%, with the average calorific Lower Heating Valuve (LHV) values of the sample at 14 MJ/kg according to the test method of ASTM D 5865. Some inconsistency is noticed in the results of calorific value, as it is not certain whether these samples were exactly at zero moisture when the chemical testings were conducted.

The moisture content (63%) of the waste in Sri Lanka is comparatively high due to the higher biodegradable portion in the waste, and it significantly differs from the condition of developed countries. A comparison is given in Table 03: Density and moisture content of MSW

Usually a waste combustion triangle gives the information regarding the suitability of waste for combustion. The combustion triangle drawn according to the Sri Lankan waste characteristics is shown in Figure 02, which gives us the information that Sri Lanka's MSW lies slightly above non auxiliary combustion range. Hence, the thermal treatment of Sri Lankan MSW needs pre drying as pre-treatment. Therefore, Integrated Waste Treatment technologies such as separation of organic bio-degradable for biological treatment, and the remaining portion for thermal treatment or Residual Derived Fuel (RDF), are favorable. Since organic waste is significant in Sri Lankan MSW, segregation at point source and a proper collection mechanism needs to be established within the country, for way forward for supporting Waste-to- Energy projects which have multiple benefits to the country.

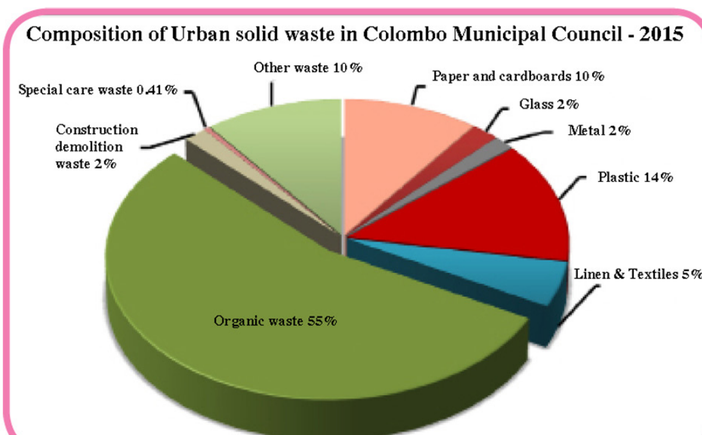

Fig 2 : Composition of urban solid waste in Colombo Municipal Council - 2015

3.0 Technology selection

The conversion processes of municipal solid waste processing to energy can be classified in to two main categories; thermal processing and bio-chemical conversion. However, these two conversion categories can be assisted with the waste (pre) processing step. Most commonly used waste-to-energy conversion processes are solid waste incineration and gasification. Waste pyrolysis is also another thermal technology option which is being tested on a large scale, and had shown significant potential for future mass scale applications. Anaerobic Digestion (AD) and

Land Fill Gas (LFG) are the two main bio-chemical conversion processes.

3.1 Waste Incineration

Incineration of biomass waste is the most common form of MSW based power generation technique. This commercially available technology is considered to be very mature, and in the range of few MW to 100 MW or more. Biomass waste is burnt (fully oxidised) and the resultant heat is used to generate high pressure and high temperature steam, which is used to drive the steam turbine (Conventional Rankin Cycle). The steam turbine extracts thermal energy from pressurized, high temperature steam, and converts to a mechanical work driving the electrical generator. There are three major types of turbines, with each one having its own specific characteristics; condensing steam turbine, extraction and back pressure steam turbine. Condensing units are designed to obtain the maximum amount of mechanical work out of a given steam generation in order to maximise electrical efficiency. This is the preference for an electricity generating plant. Extraction steam turbine unit is used to extract steam at intermediate pressure levels so that this extract steam can be used for combined heat and power

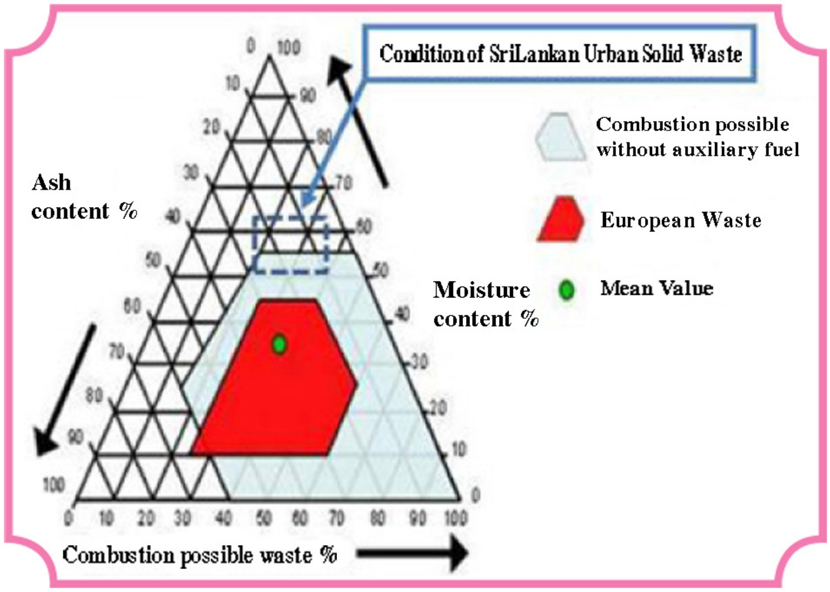

Fig 3 : Combustion triangle

systems. Back pressure design is mostly used when a constant supply of heat is required to provide steam to an industrial or commercial application. Higher exhaust steam pressure and temperature leaving the turbine results in lower shaft power.

Overall process efficiency of electricity generation (from feedstock to electricity and exclusively for electricity generation) is typically about 25%. There is an opportunity to recover some of the processes heat that cannot be fully recovered in the form of electricity, but as heat for process applications such as district heat. If this waste heat is recovered the overall process efficiency can be well above 70%. Apart from incineration, biomass waste can be co-fired with some other fossil fuel feed stock such as coal, which is done in a country like China in order to enhance the calorific value of fuel and to make the raw material homogeneous. Biomass waste can be co-fired up to 5-10% of the main feed stock without any process modification. If biomass process share is to be increased by more than 10%, extensive pre-treatment for biomass and process technology modification are required.

Stoker boilers, rotary kiln and fluidized bed boilers are the most commonly used types of boilers for biomass waste applications.

3.1.1 Stoker Boiler

Direct fire combustion of solid biomass takes place with the excess air. The hot flue gases produces steam in the heat exchange section of the boiler, and this steam is used to drive the steam turbine unit to produce electric power. Steam can also be used for the process heat purpose.

Stokers are designed to feed fuel

Table 03: Density and moisture content of MSW

Location	Density (Kg / m^3)	Moisture content	Explanations
United Kingdom	100	25	Contain high percentage of papers and empty buckets.
Europe	150		Contain low percentage of papers and more wet waste.
Developing countries	250 to 350	60	-
Some of the South Asian countries	Up to 500	60	Contain more waste from street refuses.

onto a grate where it burns with air passing up through it. This stoker located within the furnace section of the boiler also has the facility to remove ash residue after the incineration. Mechanical stokers are the traditional system of feeding fuel to a boiler, and use mechanical means to transfer and add fuel to the fire zone. Usually the fire zone is above the grate but near to the base of the furnace section. Heat is absorbed by the water tubes of the heat exchanger section as well as the water tubes inside the furnace walls. End of the grate is the facility to remove the ash residue. According to the method of adding and distribution of fuel to the furnace, there are two general types of systems; underfeed and overfeed. In both systems air is supplied from under the grate and the combustion zone. Overfeed stokers supply fuel from above or by side the combustion zone, while underfeed stokers supply fuel from under the combustion zone.

3.1.2 Rotary Kiln

In recent years, rotary kilns have played an important role in the thermo-chemical treatment of municipal solid wastes (MSW). Rotary kiln system considered to be one of the most promising incineration technologies, as it can simultaneously treat wastes as liquids or solids of various shapes and sizes, and easily achieve the flexible adjustment by altering kiln inclination, rotational speed, etc. Rotary kiln has a primary gasification chamber, followed by a secondary combustion chamber, which can fulfil the complete destruction and detoxification of wastes, at the same time minimizing emissions of dioxins and heavy metals (Li, S. *et al.*, 2002). Tumbling action inside the rotating kiln mixes waste and air more efficiently resulting in better combustion. All these unique features makes the rotary kiln irreplaceable in MSW incineration.

3.1.3 Fluidised Bed Technology

An upward blowing air jet suspends fuels during the combustion process. The tumbling action, much like a bubbling fluid, allowing solid fuel combustion air to be thoroughly mixed, providing more effective chemical reactions and heat transfer. Thus fluidized bed systems offer higher thermal efficiency and lower toxic emissions (CO, NOx) than fixed bed approaches (Stokers). However, fluidised bed technologies have higher capital and operating costs, and require significant economies of scale, so that only larger plants (>10 MW) are economically viable. Fluidized Bed Combustion system is categorized into two major groups, atmospheric systems (AFBC) and pressurized systems (PFBC), and two subgroups, bubbling-bed (BFB) and circulating fluidized bed (CFB). The major difference between bubbling-bed and circulating-bed boilers is the fluidisation velocity (higher for circulating). In circulating fluidised bed boilers (CFB) fuel is entrained by the high-velocity exhaust flow, and this entrained fuel is captured and returned to the bed for complete combustion. Pressurised CFB are in commercial/industrial applications, although atmospheric-bubbling fluidised bed boilers are more commonly used when the fuel is biomass. Fluidized bed can also be a more effective way to generate electricity from biomass with higher moisture content fuel than typical in a stoker boiler.

3.2 Gasification Technology

Gasification is a thermo-chemical process in which waste (usually biomass waste) is transformed into gaseous fuel, a mixture of several combustible gases (CO, H_2, CH_4). These combustible gases are usually referred to as syngas or producer gas. Gasification utilize less than the stoichiometric amounts of oxygen need for complete combustion. There are four major process steps. The water within the fuel is removed by evaporation during drying. In the absence of an oxidant, volatile gases, mainly CO_2, CO, and hydrocarbons are released from the dry fuel through thermal degradation in the pyrolysis process. The solid matter remaining is called char. Next is the combustion process stage providing the energy required in other process steps. In the reduction zone which is the last process step, remaining char is reduced with CO_2, H_2O and heat to form H_2 and CO. Gasification has several potential benefits over traditional solid waste incineration, mainly related to the possibility of combining the operating conditions (in particular, temperature and equivalence ratio) and the features of the specific reactor (fixed bed, fluidized bed, entrained bed, vertical shaft, moving grate furnace, rotary kiln, plasma reactor) to obtain a syngas suited for use in different applications (Arena, U., 2012). It can be utilized as a fuel gas that can be combusted in a conventional burner, connected to a boiler and a steam turbine, or in a more efficient energy conversion device, such as gas reciprocating engines or gas turbines. Its main components, carbon monoxide and hydrogen, can also be the base for synthetic fuel.

The amount of syngas throughput (thermal or electricity) needed to make these processes economically viable determines which types of gasifier might be most suitable for a particuler application. Fixed bed downdraft gasifiers are suitable for small capacity range (< 1 MW), but fixed bed updraft gasifiers can easily be scaled upto around 20 MW^{th} range. Atmospheric and pressurised fluidised bed and circulating bed, and entrained flow gasifiers can provide large-scale gasification solutions.

In "Plasma Gasification" which is considered to be an emerging technology for biomass waste gasification, biomass is fed to the boiler reactor where an electrically generated plasma arc at a very high temperature is present. When the biomass is exposed to the plasma arc it is heated to a very high temperature at which the organic compounds in the biomass is dissociated into very simple molecules later turning into sysngas consisting of hydrogen, carbon monoxide, carbon dioxide, water vapour and methane. 95-98% waste volume reduction can be achived, nevertheless this process accounts for higher parasitic load as well as very high overheads.

Gasification process needs syngas treatment before using in a combustion turbine to generate electricity. Syngas treatment unit removes fine soot, ash and sulphur compounds. Using syngas in a burner (and steam cycle) may not require complicated gas treatment right after the gasification unit. But the flue gas needs treatment before exhausting to the environment.

Table 04: Heating value of MSW

Country & Area	Boiling point of solid waste (KJ/kg) based on the moisture content
Europe	7,527
United Kingdom	10,454
China	1,850 – 6,413
Big cities in China	4,300 – 6,413
India - Middle cities	3,345 – 4,600
India - Big cities	4,600 – 6,272

3.3 Pyrolysis

Pyrolysis is the thermal decomposition of organic and synthetic waste at elevated temperatures in the absence of oxygen. Output of the pyrolysis products are carbon char, syngas and distillate oil. Process residence time and temperature govern the percentages of liquid, char and gas. Overall, the process has a high efficiency than waste incineration. The process is claimed to produce a more useful product than standard incineration. That is, gases oils and solid char can be used as a fuel, or purified and used as a feedstock for petro-chemicals and other applications. The Pyrolysis process is similar to gasification, but lags behind incineration in economic perspective due to complexity and costs.

3.4 Anaerobic Digestion Process

Anaerobic digestion (AD) is the biological degradation of waste in the absence of oxygen. The main product of anaerobic digestion is biogas, which is a methane-rich gas, typically with about 40-65%. Biogas can be burnt for power generation purposes as well as can be upgraded to natural gas as a biofuel. Even though anaerobic digestion can biodegrade virtually all types of biomass excluding woody materials, wet feedstock such as animal manure, sewage sludge, wet agricultural residues and the organic fraction of MSW are preferred. Anaerobic digestion also occurs naturally underground in landfill cover and produces landfill biogas. Landfill gas can also be collected and used in energy applications as it is AD applications. Whether the waste is treated in a sludge digestion unit, or converted to a landfill gas application, is decided by the water content (waste in sludge form) of the waste resource. The methane content in biogas is influenced by parameters like moisture content, percentage of organic fraction, temperature, and local weather. Thus, control of these parameters is a crucial requirement to have a methane rich gas for power generation. The key co-product of anaerobic digestion process is a nutrient-rich digestate, which can be used as an organic fertilizer. Anaerobic digestion is considered to be mature and well commercialized technology.

3.5 Landfill Gas

Landfill gas (LFG) is a sub category of the anerobic digestion process. LFG contains around 40 – 60% percent methane, and the rest is carbon dioxide, with less than one percent non-methane organic compounds and inorganic compounds. When waste is first deposited in a landfill, it undergoes an aerobic decomposition phase during which small quantities of methane is generated. Within around 1-1 ½ years, anaerobic conditions are established and waste is decomposed to methane and carbon dioxide by methane-producing bacteria. Typical LFG collection systems have three essential components: collection wells or trenches; a condensate collection and gas treatment system; and a blower. According to the EPA (2013) the most common method of LFG collection involves drilling vertical wells in the waste and connecting those wellheads to lateral piping that transports the gas to a collection header using a blower or vacuum induction system. Another type of LFG collection system uses horizontal piping laid in trenches in the waste. These systems are useful in deeper landfillsand in areas of active filling. Some collection systems involve a combination of vertical wells and horizontal collectors. A flare unit ensures that the excess landfill gas or the landfill gas when equipment are offline. A flare unit is a critical compotent of a landfill gas collection system as methane of landfill gas is 21 times more effective at trapping heat in the atmosphere when compared to carbon dioxide.

Collected LFG can be used in an energy recovery system to produce energy. LFG treatment is required in order to remove excess moisture, particulates, and other impurities before being used in an energy recovery system. The choice and extent of treatment system depends on LFG characteristics and the type of energy recovery system employed. Minimal treatments like dehumidification and particulate removal is sufficient for applications such as boilers and most IC engines. Some IC engines and many gas turbine and microturbine applications require further treatment to remove siloxane. Adsorption beds (activated carbon) after the dehumidification process is common in these applications.

All new "waste to energy" plants in developed countries must meet strict emission standards, including those on nitrogen oxides (NOx), sulphur dioxide (SO_2), heavy metals and dioxins. Hence, modern incineration plants are vastly different from old types, some of which neither recovered energy nor materials. Modern incinerators reduce the volume of the original waste by 95-96 percent, depending upon composition and degree of recovery of materials such as metals from the ash for recycling. Waste to energy systems have been developed in the US and Europe to burn solid waste with high caloric content resulting from large fractions of paper and other dry combustibles. The figures are for US 10,500kJ/kg, Europe 7,560kJ/kg. In Indian cities (medium sized) the range is between 3,360 to 4,620 kJ/kg of solid waste. Larger Indian cities have 4,620 to 6,300 kJ/kg of waste. Due to low caloric content of the waste in developing countries, incineration sometimes might not be viable. But it depends on the cost of pretreatment. Table 04 shows the heating value in wet basis for different regions of the world.

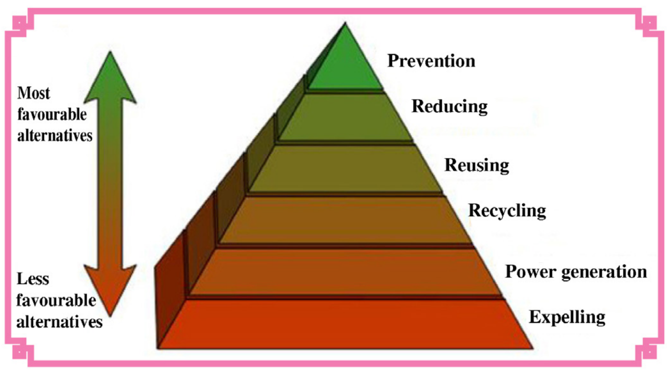

Fig 4 : Waste Management Hierachy

3.4 Electricity generation potential

The electricity generation potential under incineration and heat recovery process for MSW in Sri Lanka is estimated here. Generally incinerators have waste to electricity efficiencies of 14-28%. One of the role model plants "Reno Nord" in Denmark has reported waste to electricity efficiency of 27%. In order to avoid losing the rest of the energy, cogeneration systems are introduced in modern plants. District heating is one such method employed in Europe which is not applicable in tropical countries. From the data available in table 4, the possible electricity generation potential was calculated as in table 5. Assuming that the total waste use for incineration apart from plastic material, the combustible portion is 82% which comprises of all the organic waste, paper and paper board. Further it is assumed that the moisture content may reduce to 20% after mechanical pressing or other mean. Table 5, gives the waste to Energy potential generation data.

Table 5: Electrical Power generation potential –MW

District	Generation (Ton / day)	Sum (Ton / day)	Generation of Power (MW)	Total of power generation
Colombo	1,759	1,318	29.0	21.0
Gampaha	435	232	7.0	3.0
Kaluthara	185	131	3.0	2.0
Anuradhapura	131	70.5	2.0	1.0
Polonnaruwa	46	25.5	0.7	0.4
Kandy	350.2	231.5	5.0	3.0
Nuwara Eliya	69.8	55.3	1.0	0.9
Matale	138.5	62	2.0	1.0
Ampara	295.8	213	4.0	3.5
Trincomalee	105.5	56.75	1.7	0.9
Batticaloa	327	220	5.4	3.6
Rathnapura	235.5	116	3.9	1.9
Kegalle	101.5	68.5	1.6	1.1
Badulla	145	86.75	2.4	1.4
Monaragala	114	48	1.8	0.7
Jaffna	144.11	113.76	2.3	1.8
Killinochchi	8	5.75	0.1	0.1
Mullaitivu	11	7	0.2	0.1
Vavuniya	30	8	0.4	0.1
Mannar	53	46	0.8	0.7
Kurunegala	184	133	3.0	2.0
Puththalam	134.5	82.5	2.2	1.3
Galle	250	144.5	4.0	2.3
Mathara	134.2	106.25	2.2	1.7
Hambantota	92	48.8	1.5	0.8
Total	**5,480**	**3,630**	**87**	**56**

According to present collection of waste, 56MW of electricity could be produced by incineration, while 87MW could be generated if the total waste is collected. However, the Waste to Energy option lies somewhat below in the waste management hierarchy, which indicates order of preference for action to reduce and manage waste (Figure 3). The aim of the waste hierarchy is to extract the maximum practical benefits from products, and to generate the minimum amount of waste. In 1975, The European Union's Waste Framework Directive (1975/442/EEC) introduced for the first time the waste hierarchy concept into European waste policy.

Following the waste hierarchy will generally lead to the most resource-efficient and environmentally sound choice, but in some cases departing from it might be inevitable especially in a crisis or near crisis situation where quick and short term solutions are badly needed. However, once it comes back to normal, the hierarchy should be followed. The situation of waste management in Sri Lanka is becoming a national issue, and need some short term, quickly implementable solutions as well as long term sustainability. In that case energy recovery will be a better option as it has a potential for revenue generation from electricity which compensate the expenditure in collecting, transporting, etc. To make such projects more attractive for the investors, the energy content (electricity generation) needs to be increased in which recoverable material such as polythene and plastics should also be burnt so that it contains higher calorific value compared to paper, textile and de-watered organic material. However, this is again a deviation from the hierarchy, which needs to be reverted to in the long run. Finally it is important to note that long and intermediate term solutions as in the hierarchy, should also be implemented with the short term "quick relief" options for the sustainable development of the nation. Strong policy interventions encouraging attitudinal and behavioural changes of the public are needed to reinforce the activities of relevant institutions.

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