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Economic and Financial Feasibility Risks of Power Generation through Municipal Solid Wastes to Reduce Environmental Impacts, A Case Study based on Western Province in Sri Lanka

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Abstract: *The main objective of this paper is to explore the economic and financial feasibility risks of power generation through Municipal Solid Waste (MSW) in Western Province of Sri Lanka to minimize environmental impacts of both MSW and burning of fossil fuel for electricity generation. This research recommends the use of thermal technologies such as gasification or pyrolysis even though it associates with high capital costs and sophisticated process technology. Combination of Refuse Derived Fuel (RDF) based incineration/gasification and bio-gas based power plants are also feasible for Sri Lankan applications. Two scenarios have been analyzed and baseline financial analysis shows that both scenarios are feasible. However, sensitivity analysis shows that increase of cost and reduced project benefits by 10% will cause negative NPV value with 12% discount rate and IRR goes below cost of capital. Therefore project is associated with high risk but if implemented, it will resolve disposal issues of MSW in urban Sri Lanka with many other environmental and health benefits. The methodology used, findings and policy recommendations derived from this research can be used to analyze similar cases in other countries.*

Key words: *Municipal Solid Waste; MSW, Environment, Waste Management, Power Generation, Renewable Energy, Economic and Financial Feasibility, Risk Management, Sri Lanka.*

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I. Introduction

Municipal Solid Wastes (MSW) Management in urban areas in Sri Lanka is not functioning properly. Setting up of power plants to utilize MSW as a fuel is one possible option. Several projects have been carried out in the past on issues of disposal of MSW in Sri Lanka. These issues have included a focus on MSW collection and classification, collection method improvement, increasing awareness of the people for managing MSW within their homes etc. However, very few have focused on utilizing MSW for power generation purposes. The study focuses in finding feasibility of the use of MSW for power generation. The study uses mixed exploratory research method. Furthermore recycling, composting and producing bio gas possibilities are also studied.

A. Objectives of the Study

- To analyse the current situation of renewable power sector and MSW management sector in Colombo district in Sri Lanka.
- to explore opportunities of MSW based power generation.
- To find the economic and financial feasibility of power generation from Municipal Solid Waste by choosing an appropriate technology for Sri Lanka.

II. Literature Review

MSW is generated in a community which includes residential waste (e.g. households), commercial (e.g. from stores, markets, shops, hotels etc), and institutional waste (e.g. from schools, hospitals, etc.). MSW, commonly known as trash or garbage consists of everyday items we consume and discard. It predominantly includes food wastes, yard wastes, containers and product packaging, and other miscellaneous inorganic wastes from residential, commercial, institutional, and industrial sources. MSW represent a considerable resources that can be beneficially recovered, by recycling of materials (such as paper, plastic, metals, glass, fibers, etc.) or through recovery operations such as conversion to energy or composting of organic waste (Karthikeyan et al., 2008).

However, significant quantities of MSW is disposed of in landfills due to its low cost and free availability. Many developed countries have adopted the principle of the waste hierarchy in order to guide their policies on MSW management. According to many researchers (AIT, 2004; EPA, 2005; Tchobanoglous et al., 1993; Rapport et al., 2011; Tran et al, 2011; Gupta and Grag, 2011; Ayotamuno and Gobo, 2004; ADB, 2005a,b) overall integrated MSW management strategies are based on the four-tier MSW management hierarchy: source reduction and reuse, recycling/composting, combustion with energy recovery and land filling.
Minimizing waste generation at points where waste is originating is the first important action for managing the MSW (Zia and Devadas, 2007). Material recovery and recycling represents the best environmentally friendly way for MSW treatment and management (Onwurah et al., 2006, Kumar and Chakrabarthi, 2010). However, the recycling of material from MSW can handle only part of waste constituents such as metals, glass, and parts of paper or plastic products. Recycling of waste materials is easier if the separation area of waste is located close to the source of waste. Materials are often of lower quality or mixed with components that decrease their quality for future use. Composting is another method for handling and treating organic material from waste. The process involves a decomposition of the organic fraction of waste. It is easier to separate organic material from waste for composting than separating them for recovery of paper, plastics and similar materials. Product from composting could contain small degree of non-organic content. However it can be used in certain parts of agriculture where the requirement for such content is not too strict. Recycling of materials is preferable to treatment before energy recovery as it is economically viable and environmentally sounds (Ahmad and Firdaus, 2010; Rosan, 2009). In practice, however, even in countries with highly developed recycling infrastructures, significant amount of waste remains after recycling to make energy recovery an environmentally justified and economically viable option other than final disposal to landfill. There are many barriers to implement proper MSW management in developing countries, such as the lack of financial resources, management capacity,expertise and knowledge. Careless management of MSW affects the local, regional and global environments (Tokuc and Kokturk, 2011). The major concern is releasing of pollutants such as acid and greenhouse gases (EPA, 2006).

A. Common Unsustainable MSW Management Methods

Even though many frameworks exist for proper MSW management (Dan and Viet, 2009) most developing countries are often using very unsustainable methods as:
Open Dumping**:** An open dumping is a land disposal site where the wastes are disposed without proper control and without environmental protection.
Controlled dumping**:** It employs practices such as correct placement of the waste in thin layers and compaction and cover.
Landfills**:** Disposal of wastes in landfills is popular. The landfill gas is created by anaerobic decomposition of the waste inside the covered &sealed landfill which is a Green House Gas (GHG) agent. The production of landfill gas could continue over about 15 to 25 years after the landfill is closed. Approximately 5-20 per cent of annual global anthropogenic CH4 produced and released into the atmosphere is a by-product of the anaerobic decomposition of waste. Leach ate from landfills continues to contaminate ground water even after the site is closed and sealed. Therefore landfills are no longer a right solution for MSW disposal.

B. MSW as a Sustainable Energy Source for Sri Lanka

Petroleum based thermal electricity (4995GWh; 46%) and hydro-electricity (5636GWh; 54%) represent major share of grid connected electricity generation in Sri Lanka (Central Bank of Sri Lanka, 2010). But as thermal electricity is based on imported fossil fuels it has high negative impact on foreign reserves. Also petroleum products are not renewable power source. Due to the geo-climatic conditions, Sri Lanka is blessed with several forms of renewable energy resources. Some of them such as hydro sources are widely used and developed to supply the energy requirements of the country. Others have the potential for development when the technologies become mature and economically feasible for use. (Sri Lanka Sustainable Energy Authority, 2007). The main renewable energy resources available in Sri Lanka are biomass, hydro power, solar, sea waves, wind and MSW (Ceylon Electricity Board, 2011).

C. Technology options for MSW based Energy/Power Generation

There are several technologies to generate electricity from MSW. Basically, these involve thermo chemical processes (such as incineration, gasification and pyrolysis) and biological processes (such as landfill gas capture, controlled anaerobic digestion). Some routes of waste to energy process utilize an upgraded fuel. This can be accomplished either by separation at source followed by simple mechanical treatment such as size reduction, or by extensive mechanical treatment of MSW to produce Refuse Derived Fuel (RDF).Mass Burn Incineration technology is the controlled combustion of waste with the recovery of heat to produce steam that in turn produces power through steam turbines (Kumar,2000, Balasankari and Mathias, 2009).RDF processing involves the compaction of the waste at high temperatures and very high pressures. The organic matter is

compressed in a die to produce briquettes or pellets. The Fluidized Bed incineration utilizes modern high temperature combustion techniques to incinerate pre-processed waste which is RDF, in an integrated incinerator and boiler unit to produce high temperature and high-pressure steam. RDF Gasification is a thermal process that converts carbon-containing materials, such as coal, biomass, or various wastes, to a syngas, which can then be used to produce electric power and valuable products such as chemicals, fertilizers, substitute natural gas, hydrogen, and transportation fuels. Gasification with Organic Pulp consists of three components: waste processing, gasification and power generation. This technology provides higher rate for solid wastes into electricity. Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen or any other reagents, except possibly steam. Plasma Waste Converter (PWC) technology uses electrodes and a large amount of electric energy to produce electricity that creates an extremely high temperature environment (up to 6000 degrees centigrade). In such an environment, organic and some inorganic materials are broken down into their constituent components.
Landfill Gas to Power Generation is a traditional method to process waste. The basic concept of landfill is that the solid wastes are compacted and dumped in a large water and air proof pit. In order to prevent water leakage and air penetration, clay or geo-textile and impervious membranes are often used during the civil construction of the pit and sealing of the dumping site. In the absence of free oxygen, microbiological organisms degrade organic matter and produce landfill gas, which mostly consists of Methane and carbon dioxide. Controlled biological processes (Anaerobic digestion**)** approach involves segregation of biodegradable waste such as vegetable wastes, food wastes from MSW and using it in a biogas reactor to produce biogas.

III. Methodology

The following data collection methods have been used: Semi structured interviewees, field visits and observations are the primary data collection methods, and related documentary sources of project experiences and literatures of research discipline used as secondary data. Qualitative and quantitative documentary evidence has been used to cross validate information gathered from interviews and observations. Published and unpublished documents and records have been used for analysis.
Usage of multiple qualitative techniques for this case study research has enhanced the validity and reliability of its findings. Purposive sampling is used in this research as a sampling strategy. The respondents have been selected from several organizations of concern and are noted as under:

- Executives of Government Organizations involved in Solid Waste Power Generation related activities;
  - Central Environmental Authority
  - Provincial Council & Municipal councils officials
  - Sustainable Energy Authority of Sri Lanka
  - Ministry of Power and Energy
  - Ceylon Electricity Board
  - Energy Experts in Private and public organizations involving related activities

In addition research includes analysis of documentary sources from several areas. Documents were collected from the organizations' resource centers, reliable internet(www) sources, individual file record, university library, company reports and other printed materials (e.g. newspaper cuttings, journals, text books, conference reports, articles etc.) that were made available for the purpose of the research.
The methodology has comprised of the following steps:
First step involved the collection of background information through various reports, publications of various organizations to understand the state of MSW management in Western Province of Sri Lanka, followed by interviews with special emphasis with MSW based power generation. Qualitative interview analysis and quantitative data analysis are used. Second step is arrived at economic and financial feasibility of solid waste power production by selecting appropriate solid waste power producing technology. The followings main economic and financial measures are used in this analysis.
-Cost benefits analysis: Cost Estimations (capital cost, operating cost etc.), Financial benefit Estimations from various sources (Electricity, CER (Carbon credit), Fertilizer, Tipping charges etc.), Other non-accountable economic costs and benefits of the project (Environmental, social etc.).
-Tariff for Generated Electricity using MSW (LKR/ KWh).
- Financial Analysis; NPV, FIRR, ROI, B/C and payback period.
-Weighted Average Cost of Capital (WACC) and Financing Methods for proposed power plant.
- Sensitivity analysis (with respect to changes in cost and revenue).

IV. Current situation of renewable power and MSW management in Sri Lanka

A. Government Promotion on Non-Conventional Renewable Energy Sources

Public Utility Commission is the main responsible authority for regulating the power industry in Sri Lanka. The tariffs and the Small Power Producers Agreements (SPPA) follow two methodologies; standardized and nonnegotiable. The tariffs are cost-based and technology-specific. The developers have the option of selecting either a three-tier tariff or a flat tariff. Tariff details are noted in Table 1.

Table 1: Tariff details of non-conventional renewable Electricity generation in Sri Lanka

Technology	Flat Tariff(Cost Based) (LKR/KWh) (Non-Escallable)	All inclusive rate (LKR/KWh)	Difference of Cost and Payment (LKR/KWh)
Mini hydro	10.61	13.04	2.43
Mini hydro – Local	10.61	13.32	2.71
Wind	16.34	19.43	3.09
Wind – Local	16.34	19.97	3.63
Biomass (Dendro)	16.28	20.70	4.42
Biomass (Agri & Industrial Waste	11.32	14.53	3.21
Municipal Solid Waste	11.46	22.02	10.56
Waste Heat Recovery	6.25	6.64	0.39

Source: Public Utility Commission of Sri Lanka, 2010

According to government calculations the cost of MSW based electricity is 11.46 LKR per KWh and which is relatively low figure as compared to the wind based electricity generation cost of 16 LKR per *KWh.*

B. Current Practices of MSW Management in Sri Lanka

The current method of final disposal of MSW is open dumping in abandoned government lands. Table 2 depicts MSW collection in Sri Lanka according to the survey done by Central Environmental authority of Sri Lanka in 2005.

Table 2: MSW Collection by Municipals in each district in Sri Lanka

Province	District	Daily Collection (Mt./day)	District Percentage	Province Total	Province Percentage
Western	Colombo	1256.5	44.27%	1662.7	58.58%
	Gampaha	313.2	11.03%		
	Kaluthara	93	3.28%		
Southern	Galle	102.5	3.61%	198.46	6.99%
	Matara	68	2.40%		
	Hambantora	27.96	0.99%		
Central	Kandy	145.04	5.11%	229.22	8.08%
	Matale	32.78	1.15%		
	Nuwara Eliya	51.4	1.81%		
Wayamba	Kurunagala	73.48	2.59%	170.19	6.00%
	Puttalam	96.71	3.41%		
Sabaragamuwa	Rathnapura	49.06	1.73%	91.86	3.24%
	Kegalle	42.8	1.51%		
Uva	Badulla	57.38	2.02%	85.66	3.02%
	Monaragala	28.28	1.00%		
North Central	Anuradhapura	52.41	1.85%	74.14	2.61%
	Polonnnaruwa	21.73	0.77%		
Eastern	Ampara	57.04	2.01%	232.81	8.20%
	Baticaloa	119.33	4.20%		
	Trinco Malee	56.44	1.99%		
North	Jaffna	71.37	2.50%	93.43	3.28%
	Mannar	3.5	0.12%		
	Kilinochchi	0.92	0.03%		
	Mulathivu	8.74	0.31%		
	Vavniya	8.9	0.31%		
Total		2838.47	100.00%	2838.47	100.00%

Source **:** Central Environmental Authority of Sri Lanka, 2007

Western Province total MSW collection is around 1700MT/day and out of this amount Colombo District account for 1300 MT/day. This shows that 44% of all MSW collectionin Sri Lanka(2838 MT/day) is collected from Colombo district.

C. Technology selection for a proposing MSW based power plant

Characteristics of available MSW are first analyzed and then heating (Calorific) value of available MSW is arrived at. Appropriate technology is then selected. It is important to calculate average heat value of available waste in each Municipal Council (MC) which will give an initial idea about whether these available wastes can burn directly or not. In this report heating values (calorific values) of each MC were analyzed based on the values of energy content of MSW components given in Tchobanoglous et al., (1993). Table 3 details the calculation results, where calorific value of Colombo MC wastes is arrived at 6431.01 KJ/Kg.

Table 3: Calorific values of available MSW in local authorities in Colombo district

No	Name	Daily Garbage amount (Mt./day)	Polythene/Plastic	Bio Degradable	Long Term Degradable	Metal	Wood	Glass	Paper	Construction Waste	Meat, Fish Shop Waste	Wood Waste & Cloths	Other	Average Calorific Value (kJ/Kg)
			32799	**4180**	**6050**	**0**	**154 45**	**195**	**15814**	**0**	**4180**	**15445**	**0**	
1	Colombo MC	700	5.6	83.4	0	2	0	0.6	7	0	0	0	1.4	**6431.01**
2	Dehiwala-Mt. MC	150	7	64	1	2	10	1	6	0	0	9	0	**8457.78**
3	Moratuwa MC	150	3.82	37.09	0	1.09	0	0.55	3.27	3.27	0	49.27	1.64	**10931.23**
4	Sri Jpura MC	65	10	42	5	2	2	5	12	13	5	2	2	**8072.23**
5	Kolonnawa UC	30	5	67	4	0	10	9	5	0	0	0	0	**7035.30**
6	Maharagama UC	60	7.98	60.9	0.51	8.44	6.96	3.9	2.2	0	3.99	5.12	0	**7581.89**
7	Sithawakapura UC	7.5	5	80	2	1	1	1	6.9	1	0.1	2	0	**6665.60**
8	Homagama PS	15	3.65	82.03	3.28	0.04	1.82	1.82	3.65	1.82	0.06	1.83	0	**5971.47**
9	Kaduwela PS	34	3.57	57.14	0	7.14	4	2	7.16	6	5	7.99	0	**6756.41**
10	Kesbawa PS	15	6.67	50	6.67	3.33	13.3 3	1.67	6.67	6.67	1.66	3.33	0	**8381.80**
11	Koti/Mullariyawa PS	25	5.56	58.33	2.22	2.22	6.67	2.22	6.67	0	0.56	8.89	6.66	**7881.90**
12	Sithawakapura PS	5	6	40	40	0	4	0	4	6	0	0	0	**7310.30**
	Simple Average of (%)		**5.82**	**60.16**	**5.39**	**2.44**	**4.98**	**2.40**	**5.88**	**3.15**	**1.36**	**7.45**	**0.98**	7661.34
	Average (%) based on total weight		**5.81**	**70.13**	**0.83**	**2.27**	**2.31**	**1.32**	**6.36**	**1.36**	**0.62**	**7.77**	**1.21**	7479.68

Source: Author. Calculations are based on Tchobanoglous et al., 1993

V. Technology Selection

MSW to Energy/Power technologies have been developing gradually from traditional ones to advanced ones in the following order: Landfill gas capture, Mass bed incineration (MBI), Fluidized bed incineration (FBI), Gasification, Pyrolysis, anaerobic digestion and Plasma. Relative advantages and disadvantages of Technology are noted in Table 4.

Table 4: Technology analysis of different MSW to Power Technologies

Technology	Advantages	Disadvantages	Final Conclusions
Landfill gas capture	Suitable for available waste in Colombo as high biodegradable contents	Environmental Problems with Landfills Need high environmental standards if we apply for carbon credit which will more expensive Low Energy capture efficiency Need More lands for land filling Need to wait several years to generate bio gas	Not suitable for case of Western Province Sri Lanka as this required more lands for landfills which are not possible in Colombo urban.
Mass Burn incineration	Easy to implement plant is waste is burnable. Waste volume reduction up to 90% will reduce the land requirement for landfills.	Marginal heating values of available waste cause it is difficult to burn waste without additional fuel High environmental impact due to fluid gases emitting to atmosphere	Not suitable for case of Western Province Sri Lanka as marginal heating values of burning without additional fuel.
Fluidize Bed Incineration with RDF	Most common practices in similar countries such as India, china, Thailand etc.	High cost associate with RDF processing Environmental impact and high cost with flu gas control system	Suitable for Sri Lanka
MSW Gasification:	Energy conversion efficiency is	Plant need more control in	Possible solution for Sri Lanka.

	grater that other methods(incineration, anaerobic digestion) etc.	gasification process according to various waste types and which will increase the cost and difficulty in operation	There are advanced high tech solutions to overcome the drawbacks of this method but the cost will be very high.
Pyrolysis	Energy conversion affiance is high when compared with other technologies. Can work with mixed waste after initial separation of metals and bulky wastes	High Tech nature and need technology transfer from patented technology owners which increase the capital cost.	Possible solution for Sri Lanka if financing for project is feasible.
Anaerobic digestion:	As large biodegradable part contain in available Solid waste in Colombo , this method is more suitable	Need to separate bio degradable part and other part from waste Separation of MSW will increases cost of Electricity generation	Suitable for Sri Lanka (as high bio degradable portion of available MSW) but required separation of bio degradable part from incoming mixed MSW. There is a failure experience in Sri Lanka with this method as difficulty in sorting bio degradable part from mixed MSW.
Plasma Technology	Required to separate only inert materials (metal and building waste) all others can be applied to this process.	This is new technology and stile in R&D Stage Need time to establish the technology	This could not suitable for case of Western Province Sri Lanka

Source: Author

For an electricity generation potential of a 700 MT/day processing capacity, it is assumed that only 500 MT/day of waste can be utilized for energy generation after separating inert materials such as construction wastes, metals etc. from the total waste. Two scenarios are considered for analyzing results.

Scenario 1 presents a hypothetical power plant which uses 2MW biogas based electricity generation and 2MW FBI based power plant. The total capacity in this scenario is 4MW.

Scenario 2 presents a hypothetical power plant which uses thermal technologies (incineration, gasification or Pyrolysis) at 10MW capacity.

Scenario 1: Total Possible Power Output

It is assumed that available 700 MT/day waste is separated and bio degradable part (500 MT/day) is used to generate electricity, and to produce RDF (50 MT/day) to generate electricity using technology of incineration/gasification.

Energy output of biodegradable part by biogas production

Biogas production from MSW = 0.046 m^3/kg(Based on ADB project Bangladesh*)
Calorific value of the generated gas = 22 × 106 J/m^3
Efficiency of the electricity generator = 35%
The production of gas = 500 × 10^3× 0.046 = 23,000m^3/day

$$\text{The Capacity of the plant} = \frac{22\times10^6\times 23{,}000 \times 0.35}{24 \times 60 \times 60}$$

$$= 2.05 \times 10^6 \text{J/sec} = 2.05 \text{ MW.}$$

It is therefore possible to implement two independent power plants each with 2 MW capacities at Kolonnawa and Piliyandala (Karadiyana) dump sites.

*ADB project experience from Bangladesh (20 MW generated from 5000 MT/day MSW processing)

Energy Output Using RDF Production Capacity of 50 MT/day

It is assumed that with 700 MT/day of waste, it is possible to produce 50 MT/day of residue derived fuel (RDF). The remaining part is utilized to generate bio gas. Table 5 shows the possible electricity output by 50 MT/day RDF incineration or gasification for different calorific values.

Table 5: Possible Electricity generation in Scenario 1 with different calorific values of available wastes (50 MT/day RDF)

Calorific value (kJ/kg)	Heat output (MJ/s)	Possible Electricity output (MW)				Electricity output (MW) after 15% Own consumption			
		25% Efficiency	35% Efficiency	40% Efficiency	50% Efficiency	25% Efficiency	35% Efficiency	40% Efficiency	50% Efficiency
7500	4.34	1.09	1.52	1.74	2.17	0.92	1.29	1.48	1.84
8500	4.92	1.23	1.72	1.97	2.46	1.05	1.46	1.67	2.09
9500	5.50	1.37	1.92	2.20	2.75	1.17	1.64	1.87	2.34
10500	6.08	1.52	2.13	2.43	3.04	1.29	1.81	2.07	2.58

11500	6.66	1.66	2.33	2.66	3.33	1.41	1.98	2.26	2.83
12500	7.23	1.81	2.53	2.89	3.62	1.54	2.15	2.46	3.07
13500	7.81	1.95	2.73	3.13	3.91	1.66	2.32	2.66	3.32
14500	8.39	2.10	2.94	3.36	4.20	1.78	2.50	2.85	3.57
15500	8.97	2.24	3.14	3.59	4.48	1.91	2.67	3.05	3.81
16500	9.55	2.39	3.34	3.82	4.77	2.03	2.84	3.25	4.06
17500	10.13	2.53	3.54	4.05	5.06	2.15	3.01	3.44	4.30
18500	10.71	2.68	3.75	4.28	5.35	2.28	3.19	3.64	4.55
19500	11.28	2.82	3.95	4.51	5.64	2.40	3.36	3.84	4.80
20500	11.86	2.97	4.15	4.75	5.93	2.52	3.53	4.03	5.04
21500	12.44	3.11	4.35	4.98	6.22	2.64	3.70	4.23	5.29
22500	13.02	3.26	4.56	5.21	6.51	2.77	3.87	4.43	5.53
23500	13.60	3.40	4.76	5.44	6.80	2.89	4.05	4.62	5.78
24500	14.18	3.54	4.96	5.67	7.09	3.01	4.22	4.82	6.03
25500	14.76	3.69	5.16	5.90	7.38	3.14	4.39	5.02	6.27
26500	15.34	3.83	5.37	6.13	7.67	3.26	4.56	5.21	6.52
27500	15.91	3.98	5.57	6.37	7.96	3.38	4.73	5.41	6.76
28500	16.49	4.12	5.77	6.60	8.25	3.50	4.91	5.61	7.01
30500	17.65	4.41	6.18	7.06	8.83	3.75	5.25	6.00	7.50

Source: Author

Assuming 16500 kJ/kg and 25% efficiency in electricity generation and 15% internal usage possible electricity output from RDF incineration equals 2.03 MW.

Total Electricity output in Scenario 1 = 2.05 + 2.03 = 4 MW approximately

Scenario 2: Total Possible Power Output

The heating value of MSW in Colombo is approximately 7,400MJ/Ton. It is assumed that that the average efficiency of a waste-to-energy plant is 25% and plant factor is 80%. Thermal process of 500 MT/day, after sorting out the inert materials, is considered.

Total possible heat output = 7400 * 500 / (24*3600) MJ/s = 42.82 MJ/s
Total possible Electricity output = 42.82 * 0.25 MW = 10.7 MW
Total effective electricity output, if the plant uses 15% of electricity= 9.1 MW
Total Electrical energy output = 9.1 MW * 8760 * 0.8 = 63.77 GWh

Actual electricity output will vary according to calorific values in each dump site.

Table 6 shows the possible heat and electrical output for a 500 MT/day MSW process plant by considering different scenarios under various thermal technologies (incineration or gasification, pyrolysis) and process with different conversion efficacies.

Table 6: Possible Electricity generation in Scenario 2 with different calorific values of available wastes (500 MT/day MSW)

Calorific value (kJ/kg)	Heat output (MJ/s)	Possible Electricity output (MW)				Electricity output (MW) after 15% Own consumption			
		25% Efficiency	35% Efficiency	40% Efficiency	50% Efficiency	25% Efficiency	35% Efficiency	40% Efficiency	50% Efficiency
7500	43.40	10.85	15.19	17.36	21.70	9.22	12.91	14.76	18.45
8500	49.19	12.30	17.22	19.68	24.59	10.45	14.63	16.72	20.91
9500	54.98	13.74	19.24	21.99	27.49	11.68	16.36	18.69	23.37
10500	60.76	15.19	21.27	24.31	30.38	12.91	18.08	20.66	25.82
11500	66.55	16.64	23.29	26.62	33.28	14.14	19.80	22.63	28.28
12500	72.34	18.08	25.32	28.94	36.17	15.37	21.52	24.59	30.74
13500	78.13	19.53	27.34	31.25	39.06	16.60	23.24	26.56	33.20
14500	83.91	20.98	29.37	33.56	41.96	17.83	24.96	28.53	35.66
15500	89.70	22.42	31.39	35.88	44.85	19.06	26.69	30.50	38.12

Source: Author

There is, thus a potential of 9.1 MW Plant with 7500 kJ/kg calorific values. At Moratuwa MC the calorific value is about 10 930 kJ/Kg and there is a possibility to operate a power plant of 12 MW approximately.

VI. Economic and Financial Feasibility of Power Generation from MSW

So far the discussion has been confined to examine the selection of appropriate technology. Scenario provides a potential of 9.1 MW plant subject to specified calorific values at dump sites. This section will consider the economic and financial feasibility of power generation from MSW.

Sri Lanka has tariff related to the technology used. Two variations are used: cost based flat tariff, and all inclusive rate. The rates for energy generation using various renewable non-conventional sources are provided in Table 7.

Table 7: Cost based tariff for non conventional renewable Electricity in Sri Lanka(LKR)

Technology	Flat Tariff(Cost Based) (LKR/KWh) - (Year 1-20 - Non-escallable)	All inclusive rate (LKR/KWh) for years 1-20
Mini hydro	10.61	13.04
Mini hydro – Local	10.61	13.32
Wind	16.34	19.43
Wind – Local	16.34	19.97
Biomass (Dendro)	16.28	20.70
Biomass (Agri & Industrial Waste	11.32	14.53
Municipal Solid Waste	11.46	22.02
Waste Heat Recovery	6.25	6.64

Source: Public Utility Commission of Sri Lanka, 2010

The use of MSW stands to gain10.56 per unit. Besides, the producer has the benefit of earning carbon credits as arrived in the following section:

A. Greenhouse Gas Reduction Benefit of 500 Mt./day Dump Site

The following calculations are based on premise as contained in United Nations, Inter-governmental Panel for Climate Change (IPCC, 2006) document titled "2006 IPCC Guidelines for National Greenhouse Gas Inventories". Assumptions are based on processing of 500 tons MSW per day in each project. In absence of such a project, the waste needs to be dumped at dumping sites, which will cause to emit Greenhouse gases such as Methane and Carbon dioxide. By implementing these plants GHG emission will cease.

The IPCC guidelines recommend calculations as under:

$CH4$ Gg year $= (MSWT \times MSWF \times MCF \times DOC \times DOCF \times F \times (16/12) - R) \times (1 - Ox)$,

where,

MSWT = Total amount of refuse derivation (Gg/year)

MSWF = Share occupied by refuse transported to the disposal site

MCF = Methane formation compensation coefficient (unmanaged shallowsite: 0.4)

DOC = Weight in tons based share of degradable organic carbon

DOCF = Share occupied by DOC carbon that converts into landfill

16/12 = Conversion factor C to CH4

F = Fraction of methane in bio gas (use of the IPCC value of 0.5)

R = Methane recovery = 0

Ox = Share of methane oxidation in the upper layer of soil (use the IPCC value of 0)

Table 8 provides degradable organic carbon (DOC) values of each component of MSW.

Table 8: DOC values

Waste Type	DOC Value
Paper	0.4
Wood	0.43
Food waste	0.15
Garden	0.2
Textiles	0.24
Nappies	0.24
Sludge	0.05
Industry	0.15

Source: IPCC Guidelines for National Greenhouse Gas Inventories, 2006

DOC = 0.4 (A) +0.43 (B) +0.15 (C) +0.2 (D) + 0.24 (E)

Where, A = share occupied by paper

B = share occupied by wood and foliage

C = share occupied by food refuse

D = share occupied by refuse from gardens and parks and by non-food corrosive refuse

E =share occupied by textiles

DOC = 0.1638 for Colombo district average waste composition
DOCF = 0.014T + 0.28 (T: temperature, °C)
= 0.77 (35°C, IPCC recommendation for anaerobic bacteria layer)

CH4Emission per year = 500*365 ton /year × 0.4 × 0.16 × 0.77 × 0.5 × 16/12
= 5995.7ton/year
Calculating equivalent CO2 tons per year; CH4 creates 21 times greenhouse effect than CO2 and CO2 where equivalent factor is 20.
CH4 (ton /year) = 5995× 20
= 119,914 tons CO2 equivalent/ year
Therefore CER benefit at 10 USD per 1 ton CO2/year generates
Revenue for CER = 131,905,400LKR per year

B. Benefits from Electricity Generation:

Scenario 1(2MW*2 MSW Based Power Plant):

Assumption 700 MT/day to operate 4MW power plant;

2 MW Plant based on natural gas production;

Plant factor = 70%
Annual Electricity generation = 12.26 GWh

2 MW plant Based on RDF Incineration/gasification;

Plant factor = 80%
Annual Electricity generate =14.01 GWh
Total Annual Electricity generation = 26.28 GWh
Electricity selling price = 22 LKR/ kWh,
Total revenue from Electricity generation = 578,160,000 LKR per year

Scenario 2 (Grid supply of 9MW MSW Based Power Plant)

Assumption processing of 700 MT/day(to leave 500 MT/day after sorting) for gasification:
Power plant capacity (grid supply) = 9MW
Plant factor =81%
Annual Electricity generation = 64.15GWh
Electricity sale price = 22 LKR/ kWh,
Total Revenue from Electricity Generation = 1,411,344,000 LKR per year

Environmental Cost/Benefit of the Project: RDF based incineration plant will increase air pollution as compared to gasification. Waste incineration has historically been thought of as a major source of air pollution due to the presence of dioxins, mercury, lead, and other harmful substances. Although harmful pollutants were emitted by waste incineration facilities in the eighties, the technology and pollution control equipment has advanced so rapidly that the US EPA regards it as "a clean, reliable, renewable source of energy" and one that has "less environmental impact than almost any other source of electricity". However, the plants as discussed can reduce green house gas emission caused by regular practicing open dump sites. But defining value for this reduction is complex task and is not under the scope of this study.

C. *Social Cost/Benefit of the Project*:

The citizens get advantages of clean and pleasant environment if the dump sites are eliminated. Quantification of social benefit is not covered under the scope of this study.

D. New Employment Benefits from Proposed Power Plant

MSW based power projects are labor intensive and will generate employment opportunities. It is estimated that each plant may generate 150 jobs. Total financial value of this benefit is estimated to 53,700,000 LKR per year.

E. Capital and Operational Cost of Power Plant

Capital and operational cost used in Scenario 1 of this research are based on standard cost published by public utility commission of Sri Lanka. 284 Million LKR per MW is considered as average capital cost of investment. Also cost of separation plant is estimated to 200 Million LKR and hence total capital investment is 1.336 billion LKR per 4MW combined plant.

Operation and maintenance cost consists of three major areas:

- Power plant operation and maintenance cost (7% of power plant capital) = 79,520,000 LKR/year
- General administration and Separation plant O& M cost = 71,700,000 LKR/year
- Other variable O&M cost based on waste capacity = 25,550,000 LKR/year

- Total Operation and Maintenance cost = 176,770,000 LKR/year

Basis of operational and maintenance cost escalation:

- Average Monthly Change of CCPI (Recent Five Years) = 12.61 %
- LKR/ USD Average Monthly Change (Recent Five Years) = 2.66%
- Five year average for escalation of tariff (O&M) = (12.61 + 2.66)/2 = 7.64

F. Project Financial Analysis:

The assumptions and the financial analysis as under are on premise that project construction is expected to finish within 2 years.

- Spreadsheet to create Financial Forecast horizon of 22 years was used.
- 12% discount rate was used for discounted cash flows
- Tax calculation not conducted as projects can be easily implemented under BOI projects and Tax Exception can be applied for projects
- O&M cost escalation rates (based on inflation and USD exchange rate) given by Public utility commission of Sri Lanka
- Following financial figures were calculated and analyzed.
    - Net present value (NPV)
    - Internal rate of return (IRR)
    - Return on Investment (ROI)
    - Benefits to Costs ratio (B/C)
    - Payback period of the project
    - Sensitivity analysis for each scenario.

Table 9, shows the summary of financial analysis.

Table 9: Results of Financial Analysis: Base Line Scenario1

Financial Indicator	Total Revenue (Only From Electricity)	Total Revenue (Electricity + Tipping Charges)	Total Revenue (Electricity + CER)	Total Revenue (Electricity + Tipping Charges+ CER)	Total Cost	Scenario 1: Base Line			
						Net Benefit (Only From Electricity)	Net Benefit (Electricity + Tipping Charges)	Net Benefits (Electricity + CER)	Net Benefit(Electricity + Tipping Charges+ CER)
FNPV @ 12%	3,442,708,487	4,203,407,963	4,228,151,686	4,988,851,162	2,998,474,179	444,234,308	1,204,933,784	1,229,677,507	1,990,376,983
FIRR						19.04%	27.74%	27.99%	35.21%
ROI						14.81534544	40.18489778	41.01010825	66.37966059
B/C						1.148153454	1.401848978	1.410101083	1.663796606
Payback period						4 Years 10 Months	3 Years 10 Months	3 Years 10 Months	3 Years 3 Months

Source: Author

Net Present Value (NPV): Net present value is calculated based on following formula;

$$NPV = \sum \frac{R_n}{(1+r)^n}$$

Rn = Net Cash flow of years
r= Discount rate
n = No of Years

Discount rate of 12% was used in this research and 22 years cash flow forecast was used. For base cases of Scenario 1, financial analysis shows positive net present value (For project net benefits). Therefore project is acceptable in the point of net present value.

Internal Rate of Return (IRR): IRR is the interest rate where NPV is zero.

$$NPV = \sum \frac{R_n}{(1+r)^n} = 0$$

Project shows IRR range from 19.04% to 35.21% depending on derived benefits from the project. This IRR required comparing with Cost of Capital to get a decision. Here weighted average capital cost (WACC) was calculated using following formula. The table shows the applicable cost of capital (WACC) with different financing options.

$$WACC = Debt(\%) * CostofDebt(\%) + Equity(\%) * ReturnonEquity(\%)$$

Assuming;
Cost of Debt = 15.44 %
Return on Equity= 14%

Figure1: Project Net Benefit changes of with time

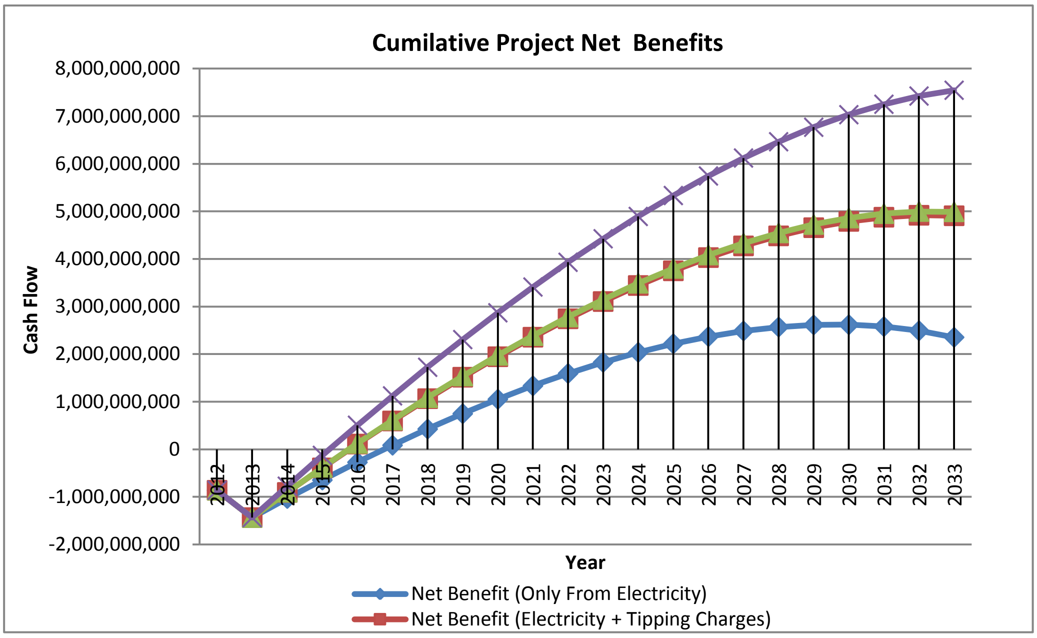

Table 10: Cost of Capital for each financing options

Debt	Equity	Cost of Capital (WACC)
10%	90%	14.144
20%	80%	14.288
30%	70%	14.432
40%	60%	14.576
50%	50%	14.72
60%	40%	14.864
70%	30%	15.008
80%	20%	15.152
90%	10%	15.296

Source: Author

Project is feasible with any of financing option and IRR is above the cost of capital in each cases. Therefore project is accepted in financial IRR point of view.

Return on Investment (ROI): ROI figure present the net project benefit with respect to total cost of investment. Discounted cash analysis used here to get present value of each cost and benefits by 12% discount factor.

ROI = (Present value of Net benefits/ Present value of Total Costs) *100%

Project ROI varies from 14.8% to 66.3%, depend on derived project benefits. This shows Project is attractive and financially feasible.

Benefits to Costs Ratio (B/C): This figure shows the project benefit with respect to project costs. Discounted cash analysis used here to get present value of each cost and benefits by 12% discount factor.

B/C = Present value of benefits/ Present value of Costs

Project B/C varies from 1.14 to 1. 66 depend on derived project benefits. This shows Project is financially feasible as total project benefits are more than total project costs.

Payback Period: Payback period intuitively measures how long something takes to "pay for itself." Payback period of project varies from 4 years 10 months to 3 years 3 months, depend on derived project benefits. This shows Project is attractive and project has the ability to pay for itself in short period of time.As conclusion on financial analysis, it shows the project is financially feasible in baseline case. However sensitivity analysis required to get complete financial understand about the scenario.

Sensitivity Analysis: This kind of project normally considers as high risk investments. Sensitivity analysis was conducted for four different cases other than baseline case calculated in above. Following sensitivity cases analyzed for this scenario.

- **Sensitivity 1: An Unfavorable condition:** increase of project cost(capital and O&M) by 10% and decrease of all project benefits by 10%
- **Sensitivity 2: An Unfavorable condition:** increase of project cost (capital and O&M) by 10% and all project benefits remains unchanged.
- **Sensitivity 3: A Favorable condition:** decrease of project cost(capital and O&M) by 10% and all project benefits remain unchanged
- **Sensitivity 4: A Favorable condition:** decrease of project cost(capital and O&M) by 10% and increase of all project benefits by 10%

The results of sensitivity analysis are shown in following table.

Table 11.Results of Sensitivity analysis

Financial Figure	Sensitivity Case	Net Benefit (Only Electricity)	Net Benefit (Electricity + Tipping Charges)	Net Benefits (Electricity + CER)	Net Benefit(Electricity + Tipping Charges+ CER)
NPV	Sensitive 1	(199,883,959)	484,745,570	507,014,920	1,191,644,449
	Sensitive 2	144,386,890	905,086,366	929,830,089	1,690,529,565
	Baseline	444,234,308	1,204,933,784	1,229,677,507	1,990,376,983
	Sensitive 3	744,081,726	1,504,781,202	1,529,524,925	2,290,224,401
	Sensitive 4	1,088,352,574	1,925,121,998	1,952,340,093	2,789,109,517
IRR	Sensitive 1	7.34%	18.99%	19.26%	26.48%
	Sensitive 2	14.41%	23.64%	23.90%	31.02%
	Baseline	19.04%	27.74%	27.99%	35.21%
	Sensitive 3	23.69%	32.30%	32.55%	40.01%
	Sensitive 4	27.78%	36.53%	36.79%	44.54%
ROI	Sensitive 1	-6.06	14.70	15.37	36.13
	Sensitive 2	4.38	27.44	28.19	51.25
	Baseline	14.82	40.18	41.01	66.38
	Sensitive 3	27.57	55.76	56.68	84.87
	Sensitive 4	40.33	71.34	72.35	103.35
B/C	Sensitive 1	0.94	1.15	1.15	1.36
	Sensitive 2	1.04	1.27	1.28	1.51
	Baseline	1.15	1.40	1.41	1.66
	Sensitive 3	1.28	1.56	1.57	1.85
	Sensitive 4	1.40	1.71	1.72	2.03
Payback period	Sensitive 1	6 years 6 Months	4 years 10 Months	4 years 9 Months	3 years 10 Months
	Sensitive 2	5 years 6 Months	4 years 3 Months	4 years 2 Months	3 years 7 Months
	Baseline	4 years 10 Months	3 years 10 Months	3 years 10 Months	3 years 3 Months
	Sensitive 3	4 years 3 Months	3 years 5 Months	3 years 5 Months	2 years 12 Months
	Sensitive 4	3 years 10 Months	3 years 2 Months	3 years 2 Months	2 years 9 Months

Source: Author

In NPV point of view Sensitivity 1 of Net benefit (Only Electricity) case shows a negative NPV which mean if project cost is increase by 10% and Revenue from electricity reduce from 10% project will be a loss. IRR is 7.34% in this case and it is far below the cost of capital. However in Sensitivity 2 case only project cost increase by 10% and expected revenue from electricity remain unchanged. In this case project shows positive NPV and 14.41% of IRR which is marginal with cost of capital. Therefore project seems to be a risk investment if project derived only electricity benefits. Project could end up with a failure in this case if strong financial Management and expected electricity is not generating due to any practical case. Therefore project need to focus on other benefits such as CER or tipping charges from Municipal councils, each show relatively same financial benefits. However as the country point of view CER benefit is the preferred choice if benefits other than CER. Baseline case of the project is financially feasible and other 2 sensitivity levels of favorable conditions also financially feasible. But there is a risk of financial failure if project goes below baseline scenario in “electricity benefit only”.Therefore it is required to secure other benefits such as environmental and health of the project.

VII. Conclusions

Composting and material recycling are the major way of managing MSW in Western Province, but the processing capacities are very low and major portion is dumped without getting any benefit from waste. Bio gas generation is also being generated at a very small scale and any of present methods are not enough to manage available MSW capacities. Implementing a MSW based power plant is a one possible option for sustainably manage the available waste. Power generation from MSW is very popular method of managing MSW in world. The characteristic of available MSW shows that it has high moisture content and low calorific values. This causes difficulty of direct burning of MSW and electricity generation. However there are several suitable technologies which can be used for the purpose. This study has identified following technologies.

- Pyroytic /gasification based technologies after initial processing of MSW
- RDF based incineration/ gasification
- Bio gas based power generation using bio degradable portion of MSW

Economic analysis shows that proposed project will be associated with several direct and indirect costs and benefits. The proposed project will provide following additional benefits: reduction of environment pollution, overcoming social issues occurred from open dumping, conversion of non-reusable waste into electricity generation, for better economic benefits, utilization of MSW to reduce the use of fossil fuel, reduction of GHG emissions, cleaner environment for a better public health (polluted water has a potential to spreading of disease), creation of many job opportunities. Table 12 provides summary of the financial analysis.

Table 12. Financial Analysis Summary

Financial Figure for baseline case	Net Benefit (Only Electricity)	Net Benefit (Electricity + Tipping Charges)	Net Benefits (Electricity + CER)	Net Benefit(Electricity + Tipping Charges+ CER)
NPV	444,234,308	1,204,933,784	1,229,677,507	1,990,376,983
IRR	19.04%	27.74%	27.99%	35.21%
ROI (%)	14.82	40.18	41.01	66.38
B/C	1.15	1.40	1.41	1.66
Payback period	4 years 10 Months	3 years 10 Months	3 years 10 Months	3 years 3 Months

Source: Author

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