American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-10, pp-69-85
www.ajer.org
Research Paper Open Access

Electrical Energy Potential from Municipal Solid Waste in Rajshahi City Corporation, Bangladesh

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Abstract: -*This paper presents the assessment of the electrical power generation potential from municipal solid waste (MSW) in Rajshahi City Corporation (RCC), Bangladesh. RCC generates huge amount of solid waste (SW) which is left very poorly managed due to crisis in governance. About 80% of organic food wastes are the major constituents of SW generated in RCC in the year 2012. Electrical energy can be produced from SW generated in RCC as a sustainable commercial solution. The average calculated value of heat content of MSW of the year 2012 based on the data of MSW of 2005 (MSW: 2005) and MSW of 2012 (MSW: 2012) is 7234.5 kJ/kg, which is sufficient to produce electricity. Integrated sustainable waste management (ISWM) has to be put into operation to harness energy from MSW. A 645.543 ton/day energy recovery Mass Burn Incinerator (MBI) system of 19.71% overall efficiency is to be used. It is found that potential of electrical energy generation from MSW in RCC during the years 2012 and 2025 is 5.336 MW and 10.568 MW respectively.*

Keywords: *-Rajshahi City Corporation; Municipal Solid Waste; Renewable Energy; Integrated Sustainable Waste Management; Mass Burn Incinerator*

I. INTRODUCTION

Fast rising population level, explosion of economic growth, rapid urbanization and the ascend in community living standards are the detrimental factors responsible for the accelerated rate of municipal solid waste (MSW) generation in developing countries [1, 2]. Solid waste management (SWM) appears to be a worldwide growing challenge in urban areas, especially in the rapidly rising towns and cities of the developing countries [3-6]. SWM reflects a foremost environmental and economic issue almost in all countries [7, 8].But municipal solid waste management (MSWM) is an extremely ignored spot mostly in urban cities of developing countries [9-15].

Due to progressive urbanization, the management of SW is appearing as a major threat to environment and public health in urban zones. But SWM is a vital environmental health service. It is a primary indispensable urban service. From the primitive era efforts have been made for safe disposal of SW. In those days habitations were scanty and land was abundant. With the rapidly growing urbanization a large number of people have started to flock in short spaces to hunt their livelihoods. As a result of the increase in density of population in the places of congregation, the waste generation per unit area has been also increased. Available land for waste disposal has been proportionately reduced. Disposal has been recognized as the most awkward functional element of SWM in developing countries. The factors causing the problems of SWM in developing countries are mainly technical and financial deficiencies [16, 17]. Other factors which hamper the effective SWM are institutional, economic and social ones [18].

In developing countries, the common problems associated with SWM are manifestation of irregular collection services and low collection coverage, poorly managed and illegal open dumping, burning without air, pollution of ground and surface water sources, breeding of vermin and flies and handling of informal waste picking or scavenging activities [84, 88]. Industrialization with rapid urbanization altered the distinctiveness of SW produced. It signifies the need of updating the solid waste management system (SWMS) to suit the waste quality, quantity and composition [15, 18, 19]. It may be noted that waste composition and characteristics varies from source to source [21].

Saving the space of disposal sites and reducing illegal open crude dumping and thereby cutting down on potential from SW can be achieved through minimizing waste generation by modifying the management practices at the source [17].

Urbanization is now a worldwide trend, but its growth is rapid predominantly in developing countries. The world urban population is anticipated to double to more than 5 billion people in the next 35 years, having 90% of this growth in the developing world [20, 22]. Statistics reveals that the world population touched 6 billion in 2001 with 46% of it dwelling in urban areas [23]. The SW generated globally was 0.49 billion tons, the estimated annual growth rate being 3.2-4.5% in developed nations and 2-3% in developing nations [24].

Every place from small house to large industry produces waste. The population and use of resources is higher in urban areas. Consequently, the waste generation rate in those areas is also high. Urban areas produce two to three times more SW than rural ones. According to the estimation of a report by World Bank, the SW generation in urban areas of East Asia alone will shift from 760,000 ton/day to 1.8 million ton/day within 25 years. Consequently, waste management costs will be approximately double from US $ 25 billion per year to US $ 47 billion by 2025 [25, 26].

The awareness of the adverse impact of improper handling of MSW has leaded the developing nations to address this issue with increasing necessity [10, 27]. Usually, about 50% of the residents in urban areas of low and middle income countries do not get MSW collection services. This is, because, municipal authorities are either unwilling or unable to provide services to all residents. The openings for the development of a sustainable MSW system are inadequate for the limitation of government budgets. Proper disposal of SW is considered as something costly [28, 29]. Municipalities are mainly responsible for MSWM in the cities. It is too difficult for them to make available an effective and efficient SWMS to the residents. The issues they face in SWMS are legal, socio-cultural, environmental, political, economic, institutional, technical and available resources. These factors are interrelated which causes the MSWM multidimensional and complex [30-33]. All these issues require to be addressed properly to accomplish a sustainable solution for MSWM. Instead of environmental legislation itself, generally, what it counts is need of implementation and/or doable substitutes [34]. Integrated Sustainable Waste Management (ISWM) Model is the model which implements an integral method to study complex and multidimensional systems. WASTE advisers on urban environment and development [35] and partners or organizations working in developing countries in the mid-1980s developed this model. Collaborative Working Group (CWG) developed it further in mid-1990s [36]. The model recognizes the significance of three dimensions in analyzing, developing or changing waste management system (WMS). The dimensions are the stakeholders who have an interest in SWM, the elements or stages of the movement or flow of materials from the generation points towards treatment and final disposal and the facets through which the system is analyzed [37-44].

It is obvious that decreasing the amount of waste generated is the technique to evade the brunt on the environment. If it does not work, recycling or re-using the waste is the best option. When these alternatives are unbefitting, burning (incinerating) the waste to generate electricity with recent advantages of combustion technology, materials and recycling technology is attractive. Utilization of landfills is the last choice [45-47].

Studies have been reported on electrical energy recovery potential from MSW generated in different countries. A study in Jordan estimated the energy content of MSW generated on its physical composition. It shows that the MSW generated is 2150 ton/day by 4.3 million population of Jordan in 1996. It would yield electrical energy of 1.77 MW/day [48].

The ratio of total MSW incinerated electricity generation (2.616 X 109^{9} KWh) to total electricity production (1.738 X 10^{11} kWh) in Taiwan during the year of 2003 was about 1.51%. It signifies effective conversion of MSW-to-energy [49].

An assessment of the electricity generation potential from MSW in Kuala Lumpur, Malaysia was conducted by Kathirvale et al. They estimated the energy potential from an incineration plant operating on SW of 1500 ton/day to be 640 kW/day [50].

In Bangladesh, Alam and Bole analyzed the possibility for the SW to electrical energy generation and its economic viability in Dhaka City. It is mentioned that the annual 1.28 million of MSW generation could produce 71 MW of electricity [51].

A system dynamics model has been developed for investigating MSW produced in Dhaka city, Bangladesh and to estimate its potential to generate electricity. Electrical energy generation potential was 456,900 MWh in 1995, which increases to 1,894,400 MW in 2025 [52]. Potential electrical energy generation was calculated in a similar way as performed by Alam and Bole [51] and Islam and Saifullah [53].

A comprehensive analysis of power production from MSW incineration plants in Taiwan since 2000 has been given by Tsai and Kuo. Waste-to-energy (WTE) power generated (i.e., 2967 GWh) in 2008 has been taken as the basis. Preliminarily calculation showed that the environmental benefit of mitigating CO_2 emissions was around 1.9 x 106 tons and the economic benefit of selling electricity was US$ 1.5 x 10^{8}[54].

MSW generation, collection and disposal data of Kampala City, Uganda was analyzed using Microsoft Excel and LandGEM model to find out the electrical energy generation potential at landfill. MSW collection of Kampala City has elevated from 7.76% in 1997 to 38.8% in 2007 of the calculated MSW generated. 70% of the MSW in the landfill is organic, enabling the landfill a high potential of methane generation [55].

A novel WTE technology was implemented in Changchun MSW power plant, China. This technology applies co-firing of MSW with coal in a grate-circulating bed (CFB). Two 260 ton/day incinerators incinerated 137,325 tons in 2006, which is nearly 1/6 of the MSW generated in Changchun. It saved landfill space of more than of 0.2 million m^3. In total, 46.2 KWh of electricity was generated, and emission of air pollutants was low [56].

Renewable power generation opportunity from MSW has been studied for Lagos Metropolis (Nigeria). The electrical energy generation potential from MSW through the route of thermo-chemical conversion has been remarkably discussed as an alternative step to landfilling and open dumping of waste commonly practiced in the metropolis. Around 442 MWe can be achieved for a population of over 16 million recorded in 2006 [57].

A mathematical model based on the composition of the waste in India has been investigated on the power generation from MSW. Linear equations have been written to represent various flow paths of waste. Then the mass balance equations have been solved for minimum cost as the main objective [58].

The energy recovery potential from MSW in Chile has been evaluated by a proposed methodological approach on the basis of a techno-economic assessment. Electrical energy options considered are landfill gas-to-energy (LGTE), direct WTE and landfill gas recovery and upgrading to feed into the grid (LGU) [59].

Bangladesh is one of the densely populated (1,125 per sq km) Least Developed Asian Countries (LDACs). MSW is generated at a very high increasing rate in the urban areas of Bangladesh mainly due to rapid urbanization and population growth. 40 – 60% of MSW are not properly stored, collected or ultimately disposed in the designated sites. This unmanaged MSW appears as an environmental, social and professional threat to city dwellers, urban planners and other concerned stakeholders [60, 61]. This scenario is distinctly visible in all the city corporations of Bangladesh, namely, Barishal City Corporation, Chittagong City Corporation, Dhaka (North) City Corporation, Dhaka (South) City Corporation, Khulna City Corporation, Komilla City Corporation, Narayanganj City Corporation, Rajshahi City Corporation, Rangpur City Corporation, Sylhet City Corporation and Gazipur City Corporation.

It is necessary to think and analyze whether waste is really waste, and if it is possible to manage MSW in such a way so that trash can be translated into cash. To find a sustainable commercial solution for MSW produced in RCC by generating electrical energy is the purpose of this paper. More specifically the objectives of the study are:

(i) To implement ISWM.
(ii) To estimate population till 2025.
(iii) To estimate the amount of MSW produced per day till 2025 and estimate how suitable it is for energy production.
(iv) To estimate the amount of energy produced by the MBI.
(v) To ascertain the possibility whether it can be established as a power generation system as well as SWMS in RCC.

The volume, the density and proportions of components of the MSW generated vary from city to city depending upon level of socio-economic development, weather and geographic location [103, 104]. Populated cities of developed countries generate more quantity of wastes and their quality, i.e., heating value is higher [62].

WTE policy not only ensures effective and efficient MSWM but also solve the problem of scarcity of electricity. This study encompasses (a) the heating values of all the components of MSW with different moisture contents, (b) the amount of energy produced for conversion into electricity and the total possible electrical energy generation and (c) the justification of the electricity generation from the MSW in RCC is feasible or not.

II. METHODOLOGY

2.1 MSW

Garbage, refuse, trash and rubbish are the synonyms to SW. The term MSW implies to SW generated from houses, streets, public places, shops, offices, hospitals and industrial processes, which are mainly the responsibility of the municipal or other government authorities [63]. Domestic waste, commercial waste, institutional waste, industrial waste and street sweeping waste belong to MSW.

Fossil fuel and other conventional energy sources supply 90% of the global energy needs, whereas other 10% comes from biomass. Excessive combustion of fossil fuel for energy generation results in serious environmental hazards such as global warming. Power generation from renewable energy sources is increasingly becoming popular for rational benefits. MSW is composed of both organic and inorganic components. Organic fraction of MSW (OFMSW) is its most useful part. OFMSW is biodegradable. MSW is generated on daily basis. MSW is considered as a new source of energy called renewable energy source as it is available in abundance and contains biomass in huge amount [64, 65].

2.2 Description of study area

July 2006 estimation shows that Bangladesh is the seventh highest populated nation, having population of 147.36 million [66]. Rapid urbanization is taking place in the densely populated country and a large quantity of people is moving from rural to urban regions each year [33, 67].

The annual increase of the total population of the country is about 1.4%, whereas the annual growth of its urban population is about 3.27%. The above comparison simply indicates rapid urbanization. The current urban population of Bangladesh is 40 million, which is about 28% of the total population of the country. It is expected that the urban population will be 116 million by 2040 which is but 50% of the total population [69]. It may be mentioned that estimated total urban population of Bangladesh was 32,765,516 in 2005 and total waste generation was 13,332.89 ton/day. In 2025, total urban population is estimated to be 78,440,000, which is 40 percent of total population. The corresponding total urban waste generation will be 47,000 ton/day [70 - 72].

2.2.1 Rajshahi City Corporation (RCC)

The head quarter of Rajshahi Division of Bangladesh is Rajshahi City. It stands on the north of the river Padma. Rajshahi Municiality earlier known as Rampur Boalia was formed a municipality in 1876. It was renamed as Rajshahi Pourashava and finally endowed the status of a City Corporation in 1991. The minimum and the maximum temperature range between 10 to 27^0C and 24 to 36^0C respectively from year to year. Rajshahi experiences the highest temperature during April and May. The annual rainfall is around 1400 mm.The current population of RCC is 795,451. The male population and the literacy rate (more than 7 years old) are 53.63% and 69.3% respectively as per 2001 census. RCC covers an area of 96.69 sq. km. The entire area is served by 384 km metalled and 96 km unmetalled road networks. There are about 118 km brick-built and 162 km unbrick-built drains in the City Corporation. RCC is distributed in 30 wards. RCC generates MSW of about 292.323 ton/day. About 50% of MSW are collected and dumped in the open dumping ground. The rest of the MSW remain uncollected and gets littered around the city.

The drains of Rajshahi City are typically uncovered and as such they collect a lot of MSW. Some of the smaller drains are lined but the main arteries are plain. These surface run-offs drains act as sewers and receive a large majority of the grey water in the city including domestic wastes and also wastes from commercial units, markets and small industries. A proportion of MSW ends up in the storm water drains which in turn flow to the field. There are facilities for door to door collection only in 13 wards. RCC possesses only one landfill (3.5 feet deep in 15.98 acre area) site located at Tikhor Vagar. Besides, there are 35 collection points and 1200 dustbins [73-76].

Migration from rural to urban area is leading to unplanned urbanization and slum development.

A huge amount of unmanageable SW is produced in these areas in all major cities of Bangladesh including Rajshahi city [68, 77]. This has given rise to a great increase in need for waste management facilities. The issue of poor MSWM is detrimental to environment, public health and safety. To ensure betterment of MSWM necessitates storage, collection and proper disposal of SW [78, 79]. The capacity of the city instruments has become inadequate to provide efficient and effective conservancy services to the rapid increase in urban population growth. About 50% of the refuse produced daily is left unattended in the six city corporations of Bangladesh. The crisis of the urban governance can be overcome by public-private partnerships for efficient MSWM [78, 80]. The MSW of RCC is only used as a material for landfilling and is a serious issue. Still rooms are there for further improvment to achieve an effective MSWM.

The demand of electricity in Rajshahi is 65 MW, whereas Power Development Board supplies only 25 MW. No electricity generation unit has been set up yet. As a consequence, the city has to face acute load-shedding and unpredictable power supply quite so often. Mills and factories are experiencing slow down due to frequent load shedding. Instant power supply appliances have got their sale sharply elevated at the outskirts. In this situation, alternative source of electric power generation is an absolute necessity [81, 82].

2.3 Integrated Sustainable Waste Management (ISWM)

MSWM is a crucial financial, environmental and social concern in the city lives of RCC. RCC cannot administer the increasing amount of waste generated. The reasons for the incapability of RCC to handle MSW are insufficient facilities, lacked environmental controls, inadequate institutional structure, poor understanding of complex systems and deficient sanitation, etc. [83-85].

A sustainable solution for SW produced in RCC is possible through ISWM. ISWM, defined by Tchobanoglous et al. as integrated solid waste management, is the choice and implementation of suitable technologies and management procedures for incorporating more environmental and economic friendly concepts to rationalize all the stages of SWM, i.e., the separation of source, gathering and haulage, transfer stations and material recovery, treatment and resource recovery and final disposal by legalizing the informal schemes, public participation and partial privatization. In industrialized nations, the general waste hierarchy is in the order: reduce, reuse, recycle, recover waste through physical, biological or chemical processes (e.g. composting, incineration) transformations and landfilling [21, 85, 86]. Thus far, Bangladesh has adapted a national strategy for ISWM solely based on the approach of 3R (reduce, reuse and recycle).

2.4 Disposal of MSW

Disposal of MSW must be properly carried out to lessen degradation of land resources and environmental health impact. MSW is generally disposed of by transporting and releasing it in open dumps in LDCAs. This is environmentally insecure. Systematic disposal methods are as described below:

2.4.1 Composting

Composting is the controlled biological decomposition of organic waste such as plants or food by bacteria, fungi, worms and other organisms under aerobic conditions. It is applicable to organic waste only. It is a very slow process. It is one of the oldest methods of SWM [87].

2.4.2 Land Filling

Land filling is one of the easiest and cheapest methods of SWM burn out mines. Dumping of SW is done in low level areas to level the ground for useful purpose. But land filling releases poisonous gases like methane causing environmental deterioration [87]. A few resource recovery plants are available in Bangladesh. Land filling is the only means in most cases of MSW disposal here [78].

2.4.3 Waste to energy (WTE) plants

The concept of biomass application for energy generation is of growing demand throughout the world. Exploitation of renewable energy resources specifically MSW is possible and it will aid to supply primary energy needs at households and for some commercial applications. Electric power can be harnessed from OFMSW. Power plants using MSW are also known as WTE plants. The technologies adopted are based on thermo-chemical and bio-chemical conversion. The three common WTE technologies are gasification, anaerobic digestion and combustion [28, 57]. Thermal treatment can reduce the volume of MSW by up to 90% and thus at a time deal with two problems: disposal of MSW and electricity generation [57, 89]. Besides, effective use of natural resources is a great step towards sustainable development [90].

2.4.3.1 Gasification of MSW

Gasification of MSW to generate energy needs thermo-chemical conversion reactions. The process brings on production of various gases like carbon dioxide, methane, steam and other byproducts such as tar and ash at elevated temperature and low concentration of pure oxygen or air. Methane is the main product in this process. Undergoing through some cleaning processes it can be directly used to run an internal combustion (IC) engine to generate electricity [57]. Gasification may reduce the mass of MSW by 70-80% and volume by 80-90% while it preserves the land area for waste land filling [91, 92]. The process involves waste collection, transportation, sorting, and conversion process, then electricity generation via a generator.

2.4.3.2 Anaerobic digestion

Anaerobic digestion is entirely a process of bio-chemical conversion for production of energy-fuel in a well-controlled enclosed space called digester. It is used to treat both dry and wet biomass resources. It implies microbial actions on bio-waste in absence of oxygen to produce biogas. The complete process is multifarious and involves a series of heterogeneous chemical reactions such as hydrolysis, acetogenesis and methanogenesis. These integrated processes degrade organic waste resulting in biogas and other energy-rich organic compounds [93, 94]. It is suitable for small scale electricity production in remote corners of developing countries.

2.4.3.3 Incineration

Incineration is another process of thermo-chemical conversion to generate energy from MSW either in the form of heat or electricity. WTE plants are fabricated for MSW disposal and electricity generation as a byproduct of the incineration. The most common WTE technology is mass burn of MSW as fuel. The MSW can be in unprocessed or minimally processed form [114, 116].

In a mass burn incinerator (MBI), incoming trucks carry the MSW into pits. The MSW is mixed by crane there and bulky or large un-combustible items are taken away. To prevent odors from being released to the environment, the MSW storage area is kept at pressure lower than atmospheric. The cranes carry the MSW to the combustor charging hopper to feed the boiler.

Heat of combustion is used to convert water into steam turning a turbine generator assembly. The steam is then condensed by traditional methods and taken back to the boiler. Residues are bottom ash, fly ash and residue from the flue gas cleaning system.

Incineration converts heterogeneous wastes into more homogeneous residues. The most significant advantage of MSW incineration is the weight decrement by up to 75% and reduction of volume by up to 90%. This can be cost-effective if landfill space is scare [95-97].

Waste incineration technology is composed of three basic components: incinerator, energy recovery unit and air pollution control system [68, 98]. Due to combustion MSW is converted into ash, flue gas (oxides of sulphur, carbon and nitrogen) and heat. Mostly the inorganic fraction of MSW forms the ash. The flue gases have to be cleaned of gaseous and particulate pollutants by incorporating a pollution control system in a complete set-up of MBI to avoid atmospheric pollution. The operating temperature range of a MBI is 800-1000^{0}C [57, 87]. Air is continuously supplied during incineration to ascertain complete combustion of the components to stable and natural molecular forms. The solid residues can either be transferred to landfills or can be used off-site for specific construction purposes after cleaning up [116].

For a sustainable commercial solution of MSW generated in RCC, an energy recovery MBI system will be used which is the same as shown by Islam and Saifullah [53]. Figure 1 shows the energy recovery MBI system for MSW of RCC.

2.5 Estimation

The SW generated in RCC is mainly non-hazardous type. These are food wastes (vegetable trimming, part of food not taken, slough of onion, green pepper, garlic, etc.), papers, packages, plastic bags, polythene, animal and fish bones, weeds, ashes, broken glass, tin, worn cloth, casing, cover of pharmaceuticals and many other things. Industrial wastes are also there. Most of the times, the wastes are piling up on roads, junction of roads, buildings, shops, schools, colleges, etc. The wastes are generated from different sources and have various components. Figure 2 (a) shows typical components of SW in RCC in % by weight during the period 1991-2001. Figure 2 (b) shows different sources of SW generation in RCC in % by weight during the period 1991-2001 [53, 99].

Urbanization of RCC has been taking place through area expansion, population growth and rural to urban migration. Right from the independence of Bangladesh in 1971, the population growth of RCC has been rising at a high rate due to migration of a large number of people from different regions of Bangladesh to RCC for education, job and business opportunities. This has given rise the total population to be increased by about 10% due to floating population from 2005 and onward [70, 100]. It may be mentioned that low income countries are, especially, facing rapid urbanization. In 1985, the world population living in urban areas was 41%, and is expected to increase to 60% by 2015 [101, 102].

The estimated total population of RCC in 1991 and 2001 was 294,056 and 388, 811 respectively.

Due to lack of information, the amount of MSW generated in RCC in 1991 and 2001 was estimated to be 53 ton/day and 113.33 ton/day [53, 99]. This estimation is based on empirical relation, i.e., the information of other cities and countries having similar socio-economic condition to that of RCC. Some simple practical procedures like counting trucks and containers were also employed to calculate MSW generation. These predictions for waste generation were, thus, not realistic [83, 21].

Without any processing MSW of RCC contains about 60% moisture, and its average calorific value is 4.63 MJ/kg. When dried in the air the moisture content of MSW reaches 5-8%, and its average calorific value then becomes 8.37 MJ/kg. And, drying MSW by flue gases makes its average calorific value stand 11.04 MJ/kg. Possible emission of SO_X, NO_X and CO during combustion of MSW is very low [53, 114].

Considering mass-fired incinerator-boiler efficiency of 0.63 and steam turbine-generator system efficiency of 0.29 the overall efficiency of the MBI energy recovery system becomes 0.183.With station service allowance of 6% and unaccounted heat losses of 5% the net electric power export (NEPE) of the years 1991 and 2001 are evaluated to be 1.103 MW and 2.358 MW respectively.

Later detailed survey was done for waste generation in both dry and wet seasons using primary and secondary data as well to estimate for 2005, 2010, 2015, 2020 and 2025 with respect to the estimated population projected for those years. Waste generation in wet season has an increase of 46% by weight is considered [70, 100]. Including 10% floating population, total population of RCC in the years 2005, 2010, 2012, 2015, 2020 and 2025 are 468,378, 606,122, 661,219, 743,865, 881,609 and 1,019,352 respectively. The corresponding waste generation in these years in ton/day is 172.83, 282.14, 325.864, 391.45, 500.77 and 610.08. Figure 3(a) shows physical composition of SW of RCC in 2005 [100]. Figure 3 (b) shows SW generated daily in RCC from different sources in % by weight in 2005 [61]. Waste generation rate (WGR) in 2005 is 0.369 kg/capita/day.

The energy content of MSW has been determined for the OFMSW only by the Modified Dulong Formula as given below [105].

$$\text{Heat (kJ/kg)} = 337C + 1428\,(H - O/8) + 9S$$

where

C = carbon (%)
H = hydrogen (%)
O = oxygen (%)

S = sulfur (%)

The value of the percentage of moisture content of individual component of MSW and data on ultimate analysis of the combustible components of MSW have been used to get finally the overall chemical composition of MSW of RCC [20, 81, 105-108].

The heat content of MSW of RCC in 2005 is found to be 8.299 MJ/kg.

In the MBI energy recovery (steam turbine – generator) plant using unprocessed MSW, 70% of heat energy is converted to steam energy. It may be mentioned that heat released from combustion of MSW is partly stored in the products of combustion (gases and ash) and partly transferred by conduction, convection and radiation to the incinerator walls and to the incoming waste. For the station or process power needs and unaccounted process heat losses allowance of 6% and 5% are considered respectively [105].

Energy available in MSW is found to be 16.601 MW and the NEPE is 3.269 MW for the year 2005. For the years 2010, 2012, 2015, 2020 and 2025 energy available in MSW are determined to be 27.100 MW, 31.300 MW, 37.601 MW, 48.101 MW and 58.600 MW respectively. And, the NEPE in those years is 5.336 MW, 6.163 MW, 7.403 MW, 9.471 MW and 11.538 MW respectively. Overall efficiency of the plant is found to be 19.69%.

Fig. 4 (a) shows physical composition of SW of RCC in % by weight in 2010 [81]. Figure 4 (b) shows SW generated daily in RCC from different sources in % by weight in 2010 [81]. Both primary and secondary data have been used collecting sample from different sources and in three main seasons: summer, monsoon and winter. In addition to domestic waste there are street sweeping, commercial including market waste, industrial waste, clinical waste and other source which includes packing materials, rags and other torn fabrics, garment materials andother trash [81, 109]. Including 10% increase for floating population, total population of RCC in 2010 was 825000 [110, 111]. WGR was 0.401 kg/capita/day. Total waste generated in RCC in 2010 was 330.825 ton/day. The heat content of MSW of RCC in 2010 is determined to be 7.673 MJ/kg. Energy available in MSW is estimated to be 29.38 MW and NEPE is 5.778 MW for the year 2010. Overall efficiency of the plant is found to be 19.666%.

Fig. 5(a) shows physical composition of MSW of RCC at landfill site in % by weight in 2012 [69]. Figure 5 (b) shows MSW generated daily in RCC from different sources in % by weight in 2012 [69]. Table 1 shows population, growth rate and area of RCC [112, 113].

Table 1: Population, Growth Rate and Area of RCC

Year	Population	Average Annual Growth Rate (%)	Area (sq km)
1981	165,821		29.83
1991	294,056	7.733	96.68
2001	388,811	3.222	96.68
Average Annual Growth Rate (1981-2001)		6.723	

For the decade (1991-2001) the annual population growth rate in RCC is 3.222%, which is considered as the low growth rate. The medium growth rate is the average annual growth rate 6.723% over the period (1981-2001). The high growth rate is the annual growth rate 7.733% over the decade (1981-1991).

Considering 2001 census population of 388,811 as the base population the projected total population including 10% increase for floating people under medium growth rate for the years 2005, 2010, 2012, 2015, 2020 and 2025 are found to be 554,851, 768,216, 874,996, 1,063,629, 1,472,640 and 2,038,936 respectively. Overall WGR in RCC in 2012 is 0.334 kg/capita/day. Total MSW generation in RCC is 292.323 ton/day in 2012. This study is mainly based on primary data. Survey was conducted during dry season only. Average weight of MSW generation has been determined considering increase of weight by 46% during wet season.

The heat content of MSW of RCC in 2012 is determined to be 6.17 MJ/kg. Energy available in MSW is estimated to be 20.875 MW and the NEPE is 4.119 MW for the year 2012. The corresponding waste generation in the years 2005, 2010, 2015, 2020 and 2025 in ton/day is 185.320, 256.584, 355.252, 491.862 and 681.005 respectively. For the years 2005, 2010, 2015, 2020 and 2025 energy available in MSW are determined to be 13.234 MW, 18.323 MW, 25.369 MW, 35.125 MW and 48.632 MW respectively. And, the NEPE in those years is 2.611 MW, 3.616 MW, 5.006 MW, 6.931 MW and 9.597 MW respectively. Overall efficiency of the plant is found to be 19.73%.

Figure 6 shows population in RCC in 1991, 2001 and estimated population in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and MSW: 2012. Figure 7 shows MSW generation in RCC in 1991, 2001 and estimated MSW generation in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and

MSW: 2012. Figure 8 shows the NEPE from MSW in RCC in 1991, 2001 and NEPE from MSW in RCC in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and MSW: 2012.

III. RESULTS AND DISCUSSION

A study on the MSW generated in RCC shows that during the period 1991-2001 domestic waste is only 30% by weight, which stands the highest value of 77.2%, 61.5% and 68.246% by weight among all the sources of MSW: 2005, MSW: 2010 and MSW: 2012 respectively. Food and vegetable waste is the dominating one among all the waste components and attains a value of 78.70%, 62.43%, 66.68% and 79.4% by weight in MSW: (1991-2001), MSW: 2005, MSW: 2010 and MSW: 2012 respectively. Grass/Leaves have a value of 10% by weight in MSW: (1991-2001) which gradually decreases to attain a value of 0.225% by weight in MSW: 2012. MSW: (1991-2001) shows paper and packages content of 6% by weight, whereas paper itself only is 6.32% by weight in MSW: 2005 and gradually decreases in MSW: 2010 and MSW: 2012. MSW: (1991-2001) contains paper and polyethylene of 4.50% by weight whereas plastics itself is 7.99% by weight in MSW: 2005 and 0.425% and 3.23% by weight in MSW: 2010 and MSW: 2012 respectively. Polyethylene is 4.50% by weight in MSW: 2010, and it has no trace in MSW: 2005 and MSW: 2012. Wood is 0%, 5.5%, 0.02% and 0.225% by weight in MSW: (1991-2001), MSW: 2005, MSW: 2010 and MSW: 2012 respectively. MSW: (1991-2001) contains clothes 1% by weight and jute/textile of 3.41, 1.11% and 2.2% by weight in MSW: 2005, MSW: 2010 and MSW: 2012 respectively. Bones has been mentioned as 0.48% and 0.37% by weight in MSW: 2005 and MSW:2012 respectively. MSW: 2010 contains bones and various other wastes of 2.05% by weight.

The heat content of MSW: (1991-2001), MSW:2 005, MSW: 2010 and MSW: 2012 are 11.04 MJ/kg, 8.299 MJ/kg, 7.673 MJ/kg and 6.17 MJ/kg respectively. It may be mentioned that percentage of waste component of MSW: 2012 is less as this MSW is landfill site and thus results in a comparatively lower value of heat content.

Waste generation is 0.369, 0.401 and0.334 kg/capita/day for MSW: 2005 in 2005 MSW: 2010 in 2010 and MSW: 2012 in 2012 respectively. It is noted that total population in 2010 from the information of MSW: 2005, MSW: 2010 and MSW: 2012 are 606, 122, 825,000 and 768,216.

The first two values resemble LGR and HGR respectively. The NEPE in 2005 for MSW: 2005, 2010 for MSW: 2010 and 2012 for MSW: 2012 are 3.269, 5.778 and 4.119 MW respectively. The NEPE in 2010 for MSW: 2005 is 5.336 MW. This value is identical to that of 2010 for MSW: 2010. The results based MSW: 2005 and MSW: 010 are more authenticas both primary and secondary data have been used directly for different seasons. The results of MSW: 2012 is based on primary data and data for wet season has been estimated from data of dry season. Moreover, the nature and quantity MSW has been changed depending on urbanization, development, industrialization and standard of living of the people with time.

It is wise to take an average value of the results obtained for MSW: 2005 and MSW: 2012 for the required MBI energy recovery system. Figure 9 shows population in RCC in 1991, 2001 and average estimated population in 2005 to 2025 for MSW: 2005 and MSW: 2012. Figure 10 shows MSW generation in RCC in 1991, 2001 and average estimated MSW generation in 2005 to 2025 for MSW: 2005 and MSW: 2012. Figure 11 shows the NEPE from MSW in RCC in 1991, 2001 and the average NEPE from MSW in RCC in 2005 to 2025 for MSW: 2005 and MSW: 2012.

A 645.543 ton/day energy recovery system with an overall efficiency of 19.71% would generate 5.336, 6.205, 8.201 and 10.568 MW NEPE in the years 2012, 2015, 2020 and 2025 respectively from MSW of RCC. The minimum heating value of MSW required for sustainable combustion is between 5.024 – 5.861 MJ/kg [115]. The heat content of MSW of RCC is 7234.5kJ/kg. A 12 MW MBI energy recovery powerplant may be installed depending on the quality and current generation of SW based on the quality and current generation of SW.

It may be mentioned thatWTE plants minimize the transport of MSW to distant landfills, reduce emissions and shorten fuel consumption [117]. Extra fuel is needed to run the process of MBI, but electric power generation his higher. Associated with this method is the drying of MSW during monsoon season. This problem can be overcome by providing a shed in a large area and using additional fuel for heating. Other methods need MSW of low moisture content and dry land which is unavailable in this area.

The main contributor to greenhouse gas (GHG) emissions during MSW incineration (MSWI) is CO_2 emissions from the combustion of inherent fossil carbon in MSW. GHG emissions can be lessened by increasing the efficiency of electricity and heat recovery. This appears to be significantly effective to optimize the energy conversion strategies of MSWI plants in China [118]. In Asia, most of the WTE plants are incineration-based. Incineration is an established and simpler technology compared to others [119, 120]. The WTE technology is considered as one of the cleanest source of technology by the U.S. environmental Protection Agency (EPA) because of the gradually diminishing levels of dioxin, furan, mercury and other volatile metal emissions over the last 20 years [121].

IV. CONCLUSIONS

- Population of RCC in the years 2012, 2015, 2020 and 2025 are 768,108, 903,747, 1,177,125 and1,529,144 and respective WGR are 309.094 ton/day, 373.351 ton/day, 496.316 ton/day and 645.543ton/day.
- Heating value of MSW of RCC is 7234.5 kJ/kg
- Net power generation during the years is 5.336 MW, 6.205 MW, 8.201 MW and 10.568 MW respectively.
- Capacity of the MBI to be used is 646 ton/day.
- Overall efficiency of the energy –recovery plant is 19.71%
- A 12 MW experimental power plant may be installed in RCC.
- Substantial reduction of waste quantity and safe disposal of SW in a controlled manner.
- Public health is ensured, environmental pollution is controlled and electric power is generated.
- MSW can be used as a renewable source of energy.
- Power generation by incineration of waste can reduce the costly fossil fuel utilization.

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FIGURES

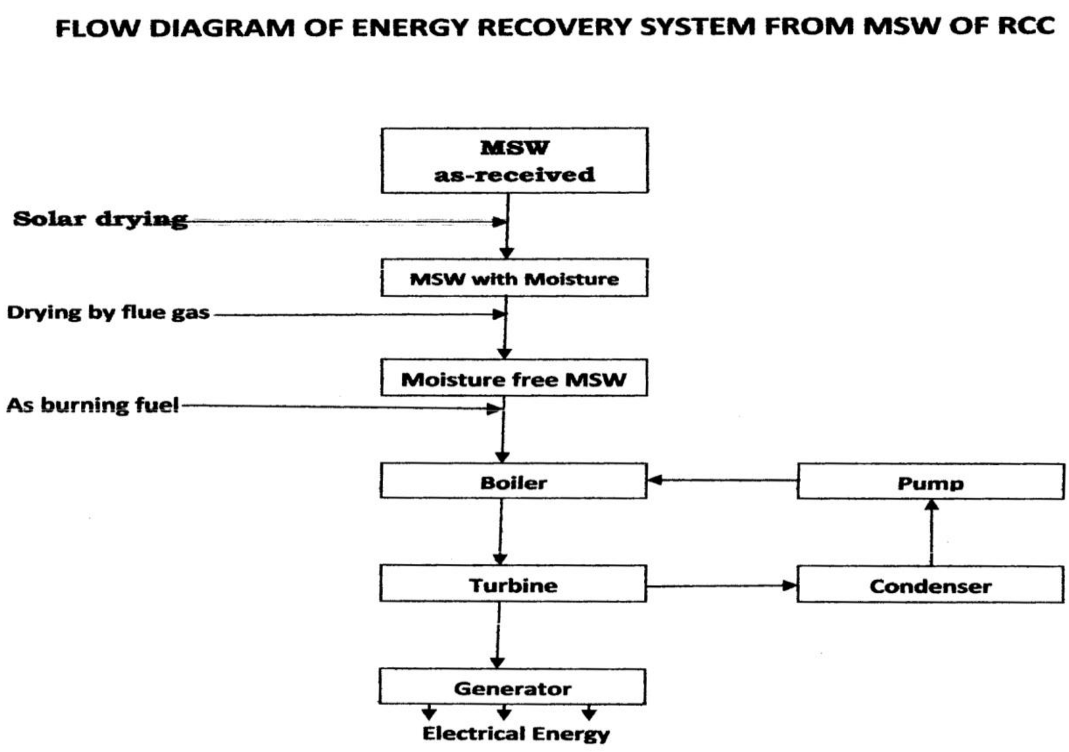


Figure 1: Energy Recovery MBI System for MSW of RCC

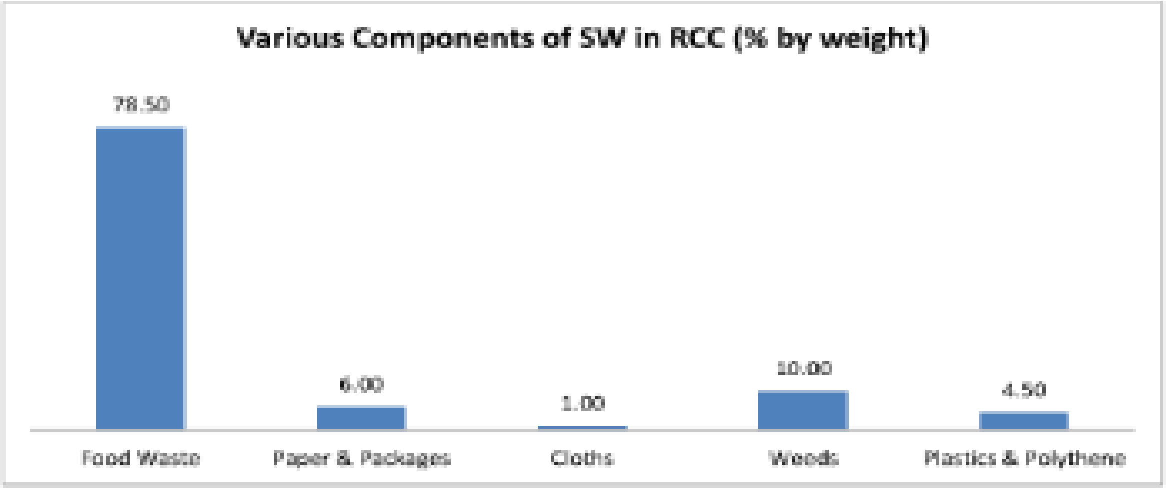


Figure 2 (a): Typical components of SW in RCC in % by weight during the period 1991- 2001

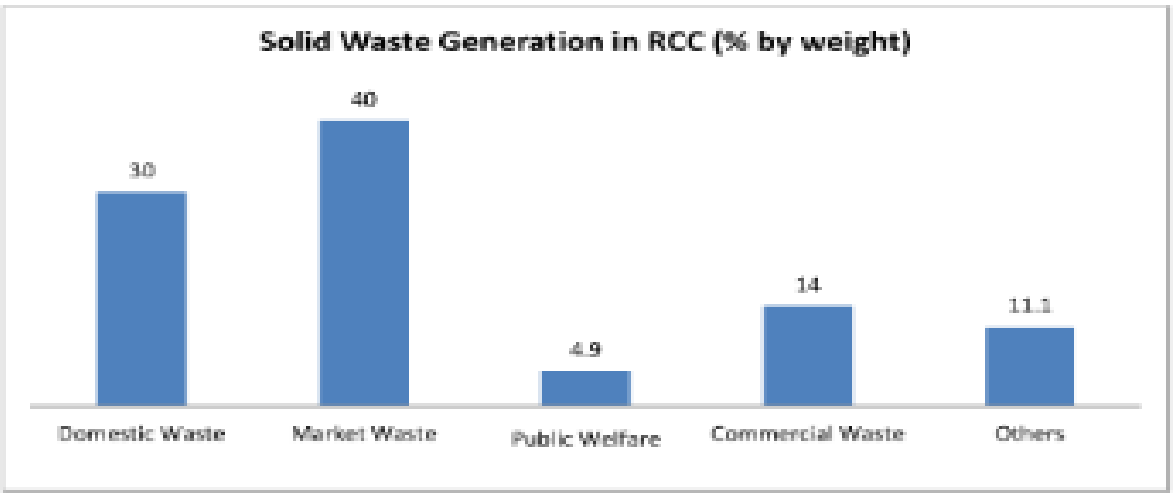


Figure 2 (b): Various sources of SW generated in RCC in % by weight during the period 1991- 2001

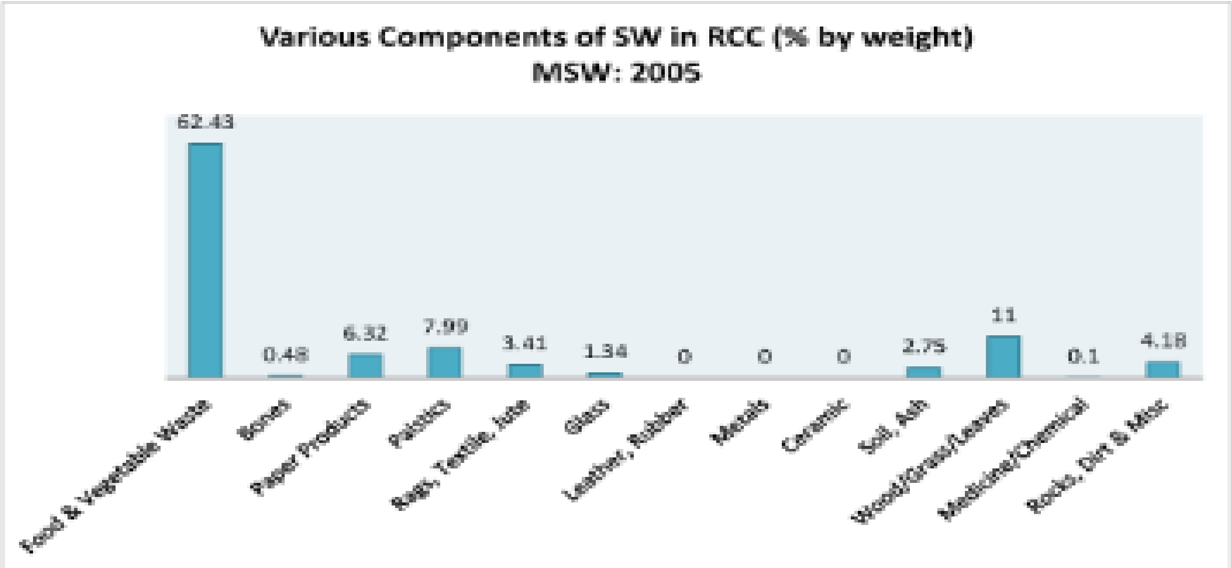


Figure 3 (a): Physical composition of SW of RCC in % by weight in 2005

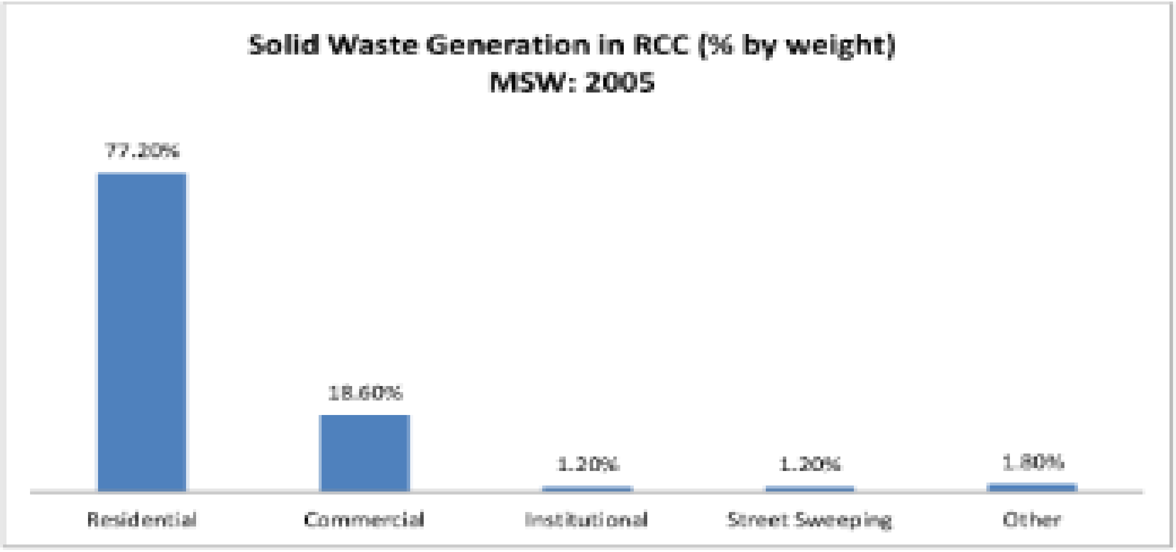


Figure 3 (b): Various sources of SW generated daily in RCC in % by weight in 2005

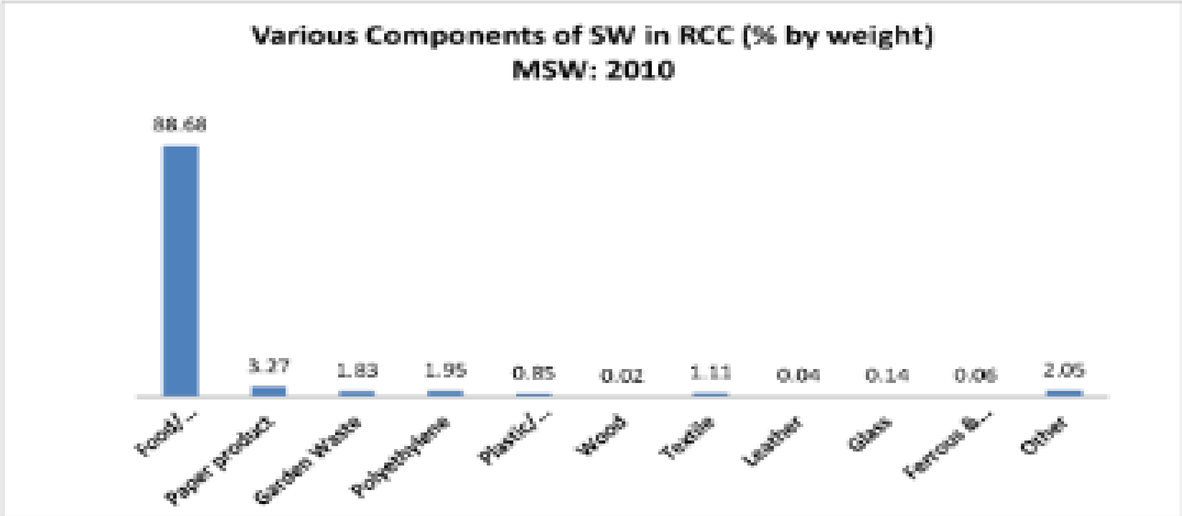


Figure 4 (a): Physical composition of SW of RCC in % by weight in 2010

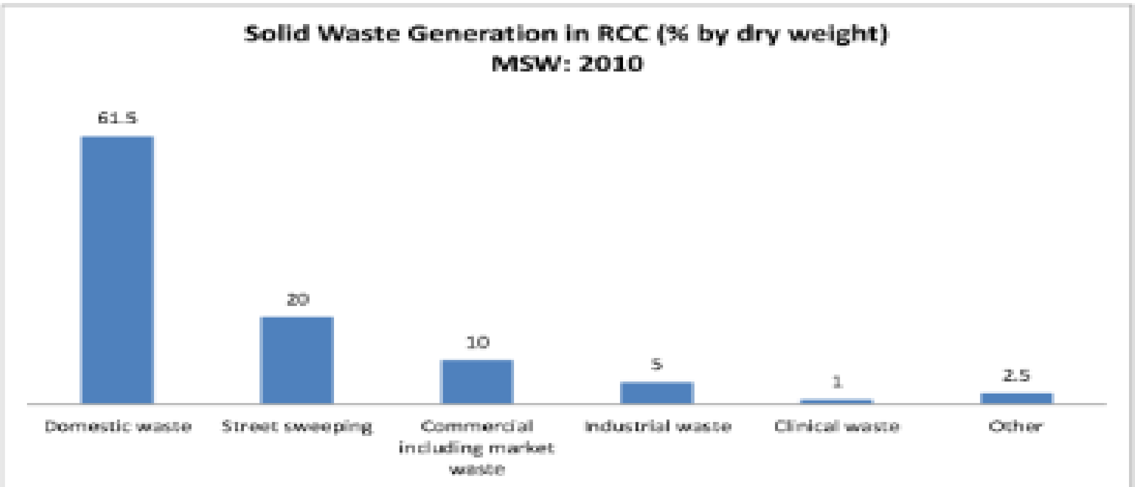


Figure 4 (b): Various sources of SW generated daily in RCC in % by dry weight in 2010

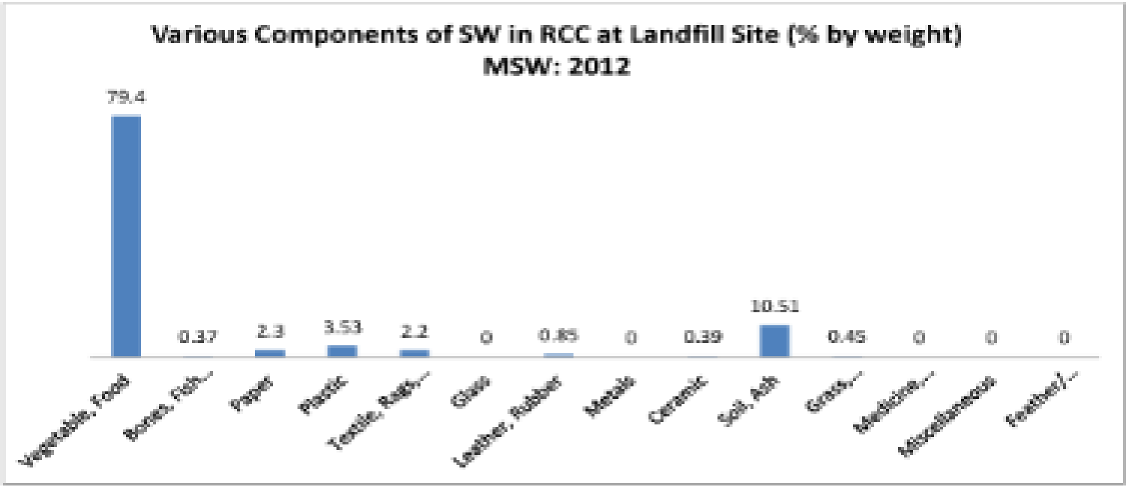


Figure 5 (a): Physical composition of SW of RCC at landfill site in % by weight in 2012

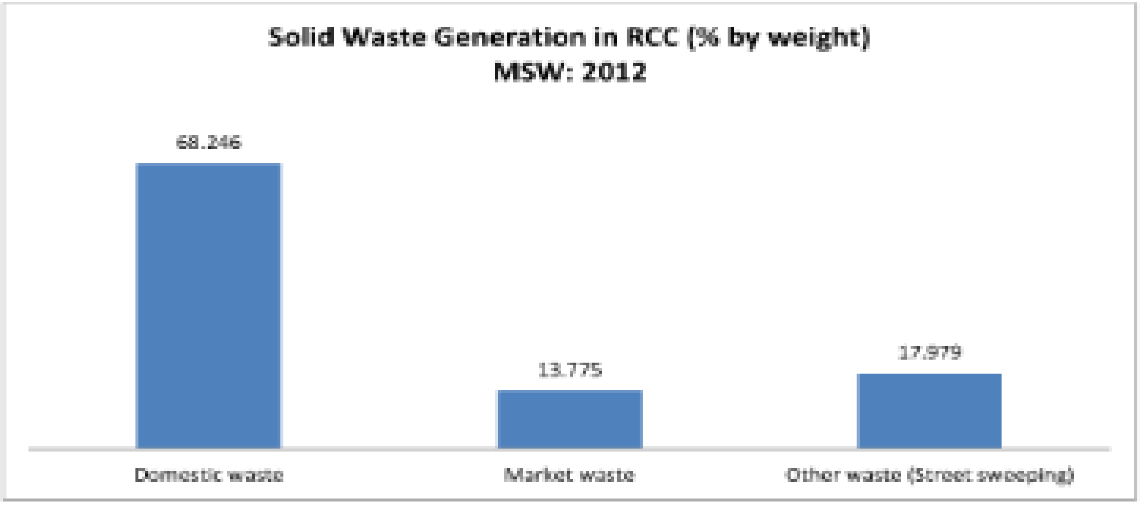
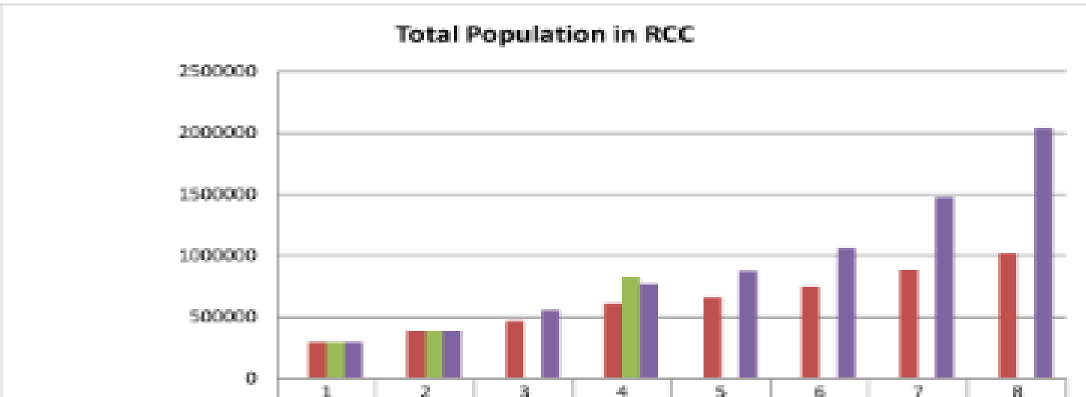
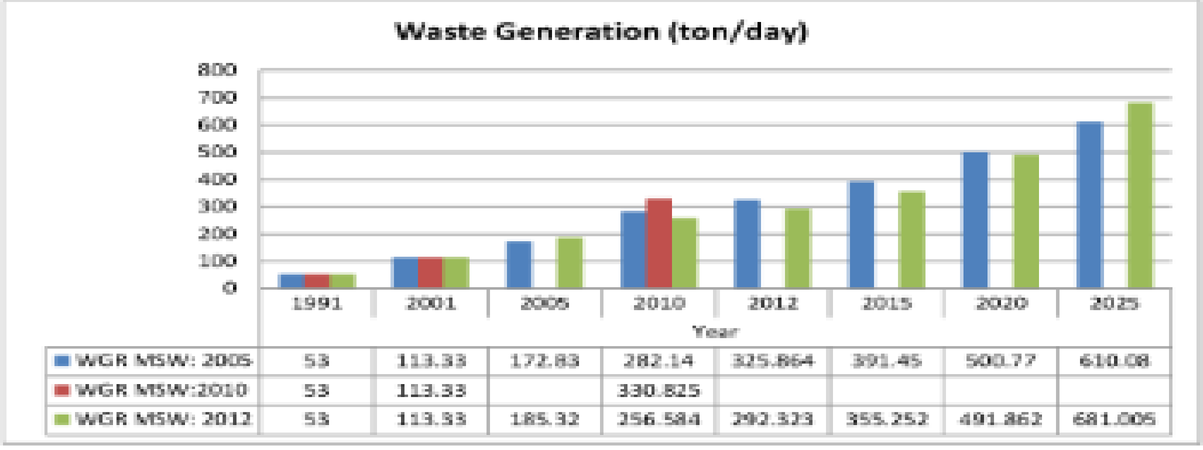


Figure 5 (b): Various sources of SW generated daily in RCC in % by weight in 2012



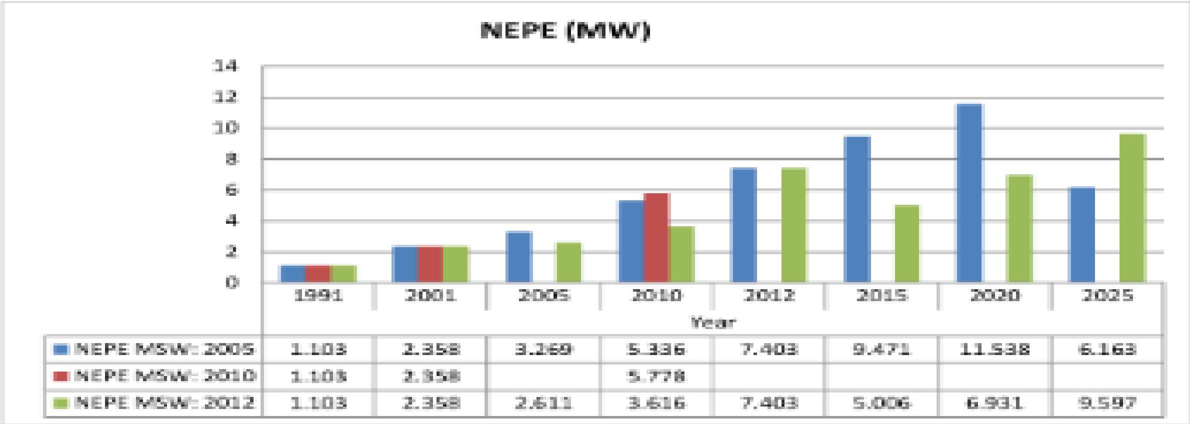
	1	2	3	4	5	6	7	8
Year	1991	2001	2005	2010	2012	2015	2020	2025
Population MSW: 2005	294056	388811	468375	606122	661219	743865	881609	1019352
Population MSW: 2010	294056	388811		825000				
Population MSW: 2012	294056	388811	554851	768216	874996	1063629	1472640	2038936

Figure 6: Population in RCC in 1991, 2001 and estimated population in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and MSW: 2012



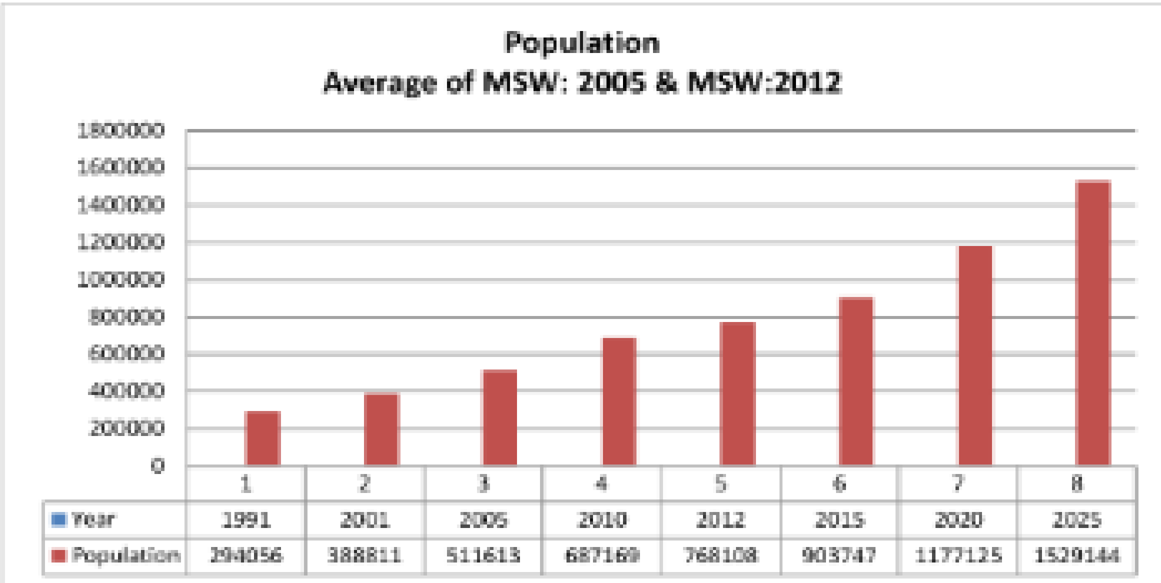
Year	1991	2001	2005	2010	2012	2015	2020	2025
WGR MSW: 2005	53	113.33	172.83	282.14	325.864	391.45	500.77	610.08
WGR MSW:2010	53	113.33		330.825				
WGR MSW: 2012	53	113.33	185.32	256.584	292.323	355.252	491.862	681.005

Figure 7: MSW generation in RCC in 1991, 2001 and estimated MSW generation in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and MSW: 2012



Year	1991	2001	2005	2010	2012	2015	2020	2025
NEPE MSW: 2005	1.103	2.358	3.269	5.336	7.403	9.471	11.538	6.163
NEPE MSW: 2010	1.103	2.358		5.778				
NEPE MSW: 2012	1.103	2.358	2.611	3.616	7.403	5.006	6.931	9.597

Figure 8: The NEPE from MSW in RCC in 1991, 2001 and NEPE from MSW in RCC in 2005 to 2025 based on information with MSW: 2005, MSW: 2010 and MSW: 2012



	1	2	3	4	5	6	7	8
Year	1991	2001	2005	2010	2012	2015	2020	2025
Population	294056	388811	511613	687169	768108	903747	1177125	1529144

Figure 9: Population in RCC in 1991, 2001 and average estimated population in 2005 to 2025 for MSW: 2005 and MSW: 2012

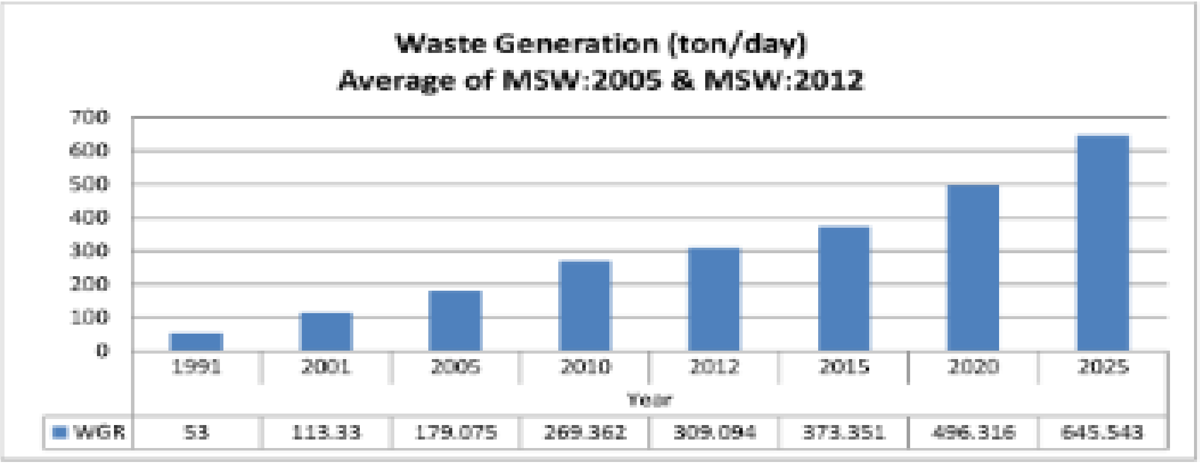


Figure 10: MSW generation in RCC in 1991, 2001 and average estimated MSW generation in 2005 to 2025 for MSW: 2005 and MSW: 2012

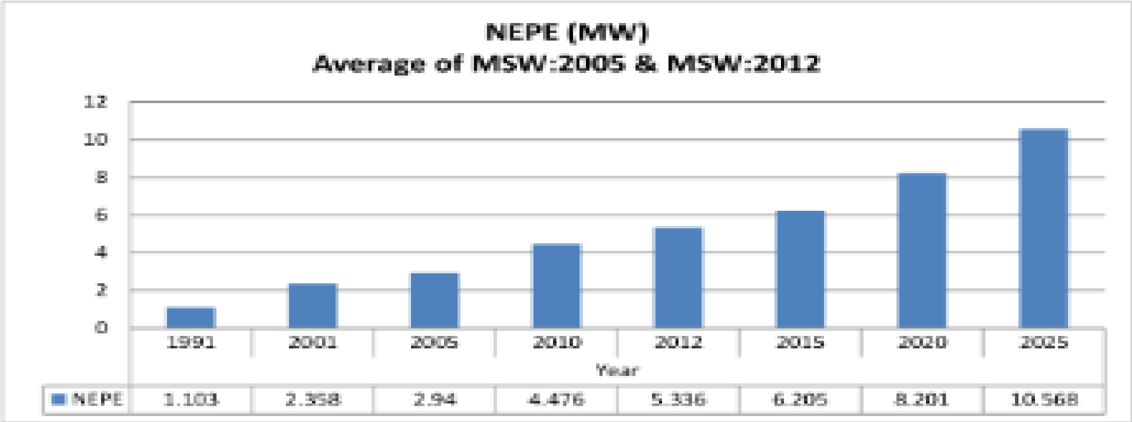


Figure 11: The NEPE from MSW in RCC in 1991, 2001 and the average NEPE from MSW in RCC in 2005 to 2025 for MSW: 2005 and MSW: 2012