feasibility of waste-to-energy recovery technologies in lahore, pakistan

abdul samad khan

Norwegian University of Life Sciences
Department of noragric
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abdul.khan@student.umb.no

Noragric

Department of International Environment and Development Studies

P.O. Box 5003

N-1432 Ås

Norway

Tel.: +47 64 96 52 00

Fax: +47 64 96 52 01

Internet: http://www.umb.no/noragric

Declaration:

I, Abdul Samad Khan, declare that this thesis is a result of my research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been appended. This work has not been previously submitted to any other university for award of any type of academic degree.

Signature………………………………

Date……………………………………

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Abstract:

Solid waste remained a no longer more problem with establishment of innovate waste-to-energy recovery technologies. In this study, try to find out the most promising energy recovery technology among the other available options for the recovery of energy from generated solid waste. The primary and secondary data on composition and quantity of waste, socio-economic, environmental related issues and on waste-to-energy technologies were collected from concerned departments by reviewing their yearly reports and conducting focus group interviews and review of published literature. The quantity of solid waste in towns of Lahore is estimated multiplying the common factor by increased population but is not correlated with economic levels of different groups. The average estimated composition of Lahore solid waste was consisted of approximately 6.7% recyclables, 28% inert and 56% organic fractions. Current composition and quantity of solid waste is favourable for various types of waste-to-energy technologies. Different available waste-to-energy options were studied deeply by considering their social-economic and environmental issues and selected the most favourable options according to their current capacities and type of composition required for the management of produced waste in Lahore. Landfill/bioreactor landfill gas production and utilization and mass burn incineration were selected to be the most favourable energy recovery technologies according to current situations. However, the landfill/bioreactor landfill gas production and utilization was considered to be the best facility which is socially acceptable, environmentally friendly and economically feasible option.

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1.0 Introduction

There is a need to reduce the current levels of waste generation and increase in material and energy recovery, which are considered as the essential steps towards an environmental-friendly waste management system. Landfill is also no longer the first choice for disposal among the other methods such as recycling, composting and incineration, but a last step after all possible material and energy recovery in solid waste management practices. Initially, incinerators globally were used to reduce waste mass but energy is being recovered from incinerators nowadays. Electricity and heat is produced from the recovered bio-gas from landfill. From a mass view point of material recycling, composting of organic waste is considered as the most important system (Marchettini et al., 2007).

The problems arising from solid waste can be solved by using innovative technologies. Nowadays, different types of waste-to-energy (W-T-E) schemes are available through which energy can be efficiently recovered and used, such as anaerobic digestion (i.e. both dry and wet, thermophilic and mesophilic), thermal conversion (i.e. rotary kiln incineration, mass burn incineration, starved air incineration, fluidized bed combustion, pyrolysis and gasification, plasma technology, thermo-chemical reduction, refuse derived fuel) and landfilling (i.e. landfill gas utilization and bioreactor landfill). Each type of technology handle the specific composition and quantity of solid waste (Tatamiuk, 2007). It seems to be difficult to propose suitable waste management plans and technologies without determining the quantity and composition of generated waste (Idris et al., 2004).

Globally, wastes are used to produce electricity and fertilizer or used for recycling. Recently, Europe and United States (US) are recycling waste about 41% and 32%, respectively. China is also investing US 6.3 billion dollar to achieve 30% recycling of its waste by 2030 (State Bank of Pakistan, 2009). Currently, out of more than 800 incineration plants working throughout world, about 236 are in Japan and 400 in Europe. The plants in Europe have capacity to provide electricity approximately 27 million inhabitants (State Bank of Pakistan, 2009). There are two methods used for the treatment of solid waste in India, namely the composting (vermin-composting and aerobic composting) and waste-to-energy technologies (pelletization, biomethanation and incineration). Although the latter method is working successfully in the developed world, it is relatively new in India (Sharholy et al., 2008).

One private organization named Lahore Compost Limited is operating in Lahore, which utilizes organic waste of the city. It is an aerobic composting plant and has the capacity to convert 1000 tons of organic waste per day to compost which is utilized for soil conditioning. This project is now registered as a Clean Development Project. Other large cities in Pakistan are also thinking about such type of plant to reduce their generated organic waste. The Lahore facility was imported from Belgium and complies with European regulations. This is the 1st time the waste handling technology has been introduced to Pakistan (EFCI, 2010).

In Pakistan, waste can be used as a resource for the economy. Taking this point of view, some of the private firms and non-governmental organizations (NGOs) are closely working with this industry. They collect the waste and reprocess it for further use. Similarly an NGO established a recycling facility in Karachi where they produce refused derived fuel (RDF) having a concept of waste-to-energy production. Another NGO is also working in the main cities of Pakistan converting wastes to pellets. The extracted liquid from organic waste is enriched with nutrients and sold in the market as plants fertilizer. In the whole country there are limited numbers of such kind of waste handling organizations. That is why the government should take serious responsibility to this sensitive issue and create opportunities to convert solid waste to energy and other useful purposes (State Bank of Pakistan, 2009).

In Pakistan, a number of illegal, and even some official waste disposal sites, are environmentally unacceptable. They operate without taking any potential measures to avoid infiltration of leachate from open landfill dumping sites to the groundwater. Almost none of the dumping sites have landfill gas excavation system, collection and treatment of leachate. The solid waste treatment and disposal technologies (like incineration, composting and sanitary landfills) are relatively new concepts in Pakistan. Collected waste is commonly dumped on open disposal sites or burnt in open air to reduce its volume, which contributes to air pollution. “At present, there are no landfill regulations or standards that provide a basis for compliance and monitoring, but national guideline for these standards are being prepared by the consultant under the National Environmental Act Plan Support Program (NEAPSP)” (Joeng et al., 2007). The problems associated with solid waste “more fundamentally, arise from the lack of comprehensive waste management system and strategy that encompasses functions of governance, institutions, finance and technology” (Joeng et al., 2007).

In Pakistan there is a great difference between the generated and collected waste at the disposal sites. According to the Pakistan Environmental Protection Agency (2005) only 51-69% of the generated waste is collected and the rest remains in the streets or collection points (Joeng et al., 2007). It is estimated that approximately 55,000 tons waste is generated per day (Pakistan Environmental Protection Agency, 2005), based on the assumption that 0.6 to 0.8 kg waste is produced per capita per day. The increase in environmental degradation as a result of industrialization and urbanization causes economic losses (EPS, 2005).

There is no waste sampling and analysis performed in Pakistan. On all disposal sites (i.e. Mehmood Booti, Saggian and Bagrian disposal sites) except one i.e., Mahmood Booti, no weighing facilities are currently operating. Currently at different steps of solid waste management, scavengers play main role in separating the recyclables (Pakistan Environmental Protection Agency, 2005). Hazardous waste from hospitals and industries is treated as normal waste. Due to open burning (especially plastic) and open dumping, atmospheric air is being polluted (Pakistan Environmental Protection Agency, 2005). Further, stagnant ponds which provide breeding ground for mosquitoes and flies with ultimate risks of malaria and cholera are formed due to clogging of drains (Pakistan Environmental Protection Agency, 2005).

The amount of waste production is directly linked with increase in gross domestic production, steady increase in population growth rate and change of life style (The World Bank, 2007). Energy can be produced and utilized from the generated solid waste, especially in mega cities of Pakistan like Lahore, Karachi and Multan etc. Due to lack of management, the generated waste which has potential to generate energy, is dispersed all-around the environment. Energy can be recovered from it in the following forms e.g. bio-gas, electricity and fertilizers etc. These beneficial components are currently either being released into the atmosphere due to open burning and dumping or into the ground water due to poor landfill conditions. In most cities, largest part of the budget is fixed for solid waste services. But still approximately less than 50% of the generated solid waste is collected, but instead improperly disposed at landfills, road sides or burnt openly without taking care of air and water pollution control (Energy Sector Management Assistance Program, 2010).

The socio-economic, environmental and human health components are directly linked with environmental practices. Solid waste management is one of the main environmental practices that is negatively affecting the socio-economic-ecological and well-being health due to poor handling and treatment of generated waste. According to a recent study by Batool et al., (2006) in Lahore, Pakistan, if the recycling practices are adapted as an industry, they can generate revenue of Rs. 530 million, i.e., US$ 8.8 million/year with the saving of large quantities of energy and natural resources. Different types of benefits could be achieved, if energy recovering and natural resources are considered as creation of jobs, reduction of environmental impacts and provisions of economic opportunities.

Limited awareness and financial and institutional capacities are hindering the exploration of different types of waste treatment technologies and in this regard only very few number of treatment plants i.e. composting plants are operating in Pakistan. There is, therefore a need to analyze the different types of waste-to-energy technologies used in the world regarding their socio-economic and environmental considerations and evaluate the most suitable treatment facility that will be acceptable on the basis of above described parameters.

1.1 Aim of the study

The aim of current study is to try to find out the most cost effective and least polluting energy recovery technology among the other available options for the recovery of energy from generated solid waste. The selection of technology will be based on the local conditions of the study area. This will help to develop a solid waste management system of Lahore, Pakistan that will be environmentally effective, economically affordable and socially acceptable. In addition, this will ensure a better quality of life of present and future generations.

The leading objectives are to:

1) Identify the current solid waste generation from different towns in Lahore.

2) Evaluate the socio-economic-environmental potentials to implement energy recovery principles in different solid waste management technologies in Lahore.

Following research questions will be treated in different parts of the study in order to reach the objectives.

1.1.1 Research questions

1. What are the composition and quantities of generated waste from different towns?
2. What are the economic and population trends in each town that produces solid waste?
3. What are socio-economic and environmental problems associated with solid waste system and their link with the presence and absence of energy recovery principle?
4. What are the findings of already conducted studies by the developed world societies about the energy recovery technologies for the different kinds of generated and collected waste, and their energy potential against the reality of big city of Pakistan like Lahore?

2.0 Literature review

2.1 Composition of solid waste and waste-to-energy recovery technologies

Solid waste composition plays a vital role while developing a solid waste management system. This management system may include the recycling, composting, landfilling and any other waste-to-energy technology strategies. Specific type of energy recovery technology depends on particular components of waste stream. So the technologically and economically suitability of certain waste-to-energy scheme is defined by characteristics of waste stream (Tatamiuk, 2007).

2.1.1 Anaerobic digestion

Anaerobic digestion facility has the ability to deal with degradable organic fractions of waste streams. Suitable internal system conditions are provided such as warm and moist to microorganisms to degrade organic waste to stabilize end product, which is free from pathogens and act as a soil conditioner (Varma, 2009). For anaerobic digestion quantity of organic components present in solid waste stream has an important value (Tatamiuk, 2007).

2.1.2 Incineration

Incineration is the combustion of solid waste stream to produce gases, particulate emissions, ash and energy. Efficiency of incineration facility is directly linked with waste composition such as calorific values, inert fraction and moisture content conditions (Varma, 2009).

2.1.3 Pyrolysis and gasification

Pyrolysis and gasification (P&G) technologies are designed to convert biomass that is rich in carbonaceous materials into carbon monoxide (CO) and hydrogen at high temperature by reacting with raw material under oxygen control environment (Varma, 2009). Pyrolysis technology is considered suitable for paper rich solid waste stream. These facilities are well known for mixed municipal solid waste with high amount of organics (Tatamiuk, 2007).

2.1.4 Landfill gas (LFG) collection and utilization

Landfills produce landfill gas by the degradation of organic matter under anaerobic conditions. The evaluation of any landfill gas recovery project is highly effected by the composition of waste, specifically the organic fraction, moisture level, and the "degradation" factor of different waste components. Like those landfills with high food waste contents, relatively faster decay to generate landfill gas over short period of time (SCS ENGINEERS, 2005).

2.2 Choice of feasible technology and other affecting parameters

The choice of a particular technology for the treatment of solid waste stream relies on important parameters such as environmental friendly, techno-economic viability, areal conditions and sustainability (Varma, 2009). “The important parameters that are considered generally for a sustainability analysis are the quantity of waste that can be handled, physical, chemical and biological characteristic of waste, land and water requirements, environmental sensitivity to locations, environmental implementations, capital investment, operation and maintenance costs, cost recovery, product utility, byproduct usability or reject disposal, requirement of pollution control installation etc.” (Varma, 2009). Solid waste management system is also affected by social, economic and political outcomes. Varieties of solid waste management rules and regulatory requirements of a country play crucial role while it’s waste management system development (Zaman, 2010).

2.3 Sustainable waste management

Solid waste management has close relationship with socio-economic and environmental parameters. The sustainable development in solid waste sector is interconnected with best solid waste management strategies. Nowadays, due to innovative technological development and change in perceptions, solid waste stream is used as an energy recovery resource, which also ensures recovery of natural resources. Heavily dependent on the natural resource extraction and without paying attention to the waste generation and its management, can lead to an adverse development of situation. Dramatic changes in global climate compel us to use of natural resources in a sustainable way and develop technologies for generated waste that ensure sustainability in real sense (Zaman, 2009).

2.4 Pakistan legal framework for solid waste management

Currently, concerning solid waste management implemented rules and regulations in Pakistan are expired/outdated. Guidelines (of 1998) providing detailed information regarding handling of hazardous waste is not yet properly enforced. Generally, hazardous waste is intermingling with municipal solid waste and openly dumped to the landfill sites. To some extent, hazardous waste is simply buried but without any precautionary measures. There is an urgent need to enforce solid waste management and hazardous waste laws and hazardous waste should be collected separately from generation points (Mahar et al., 2007). Inadequate solid waste treatment practices are adopted, such as disposing of most of the generated waste in low lying area such as in ponds, and the recyclables are only recovered by scavengers (Mahar et al., 2007). Treatment technologies like composting, incineration and landfills are relatively new in Pakistan. Open dumping of waste is commonly practiced and the volume of waste is reduced through open incineration. Open dumping of waste itself and its incineration are the major sources of air pollution in Pakistan. But the National Environmental Action Plan Support Program (NEAPSP) formulated the national guidelines for solid waste management standards (Joeng et al., 2007).

2.5 Waste-To-Energy (W-T-E) treatment options

2.5.1 Anaerobic digestion

Anaerobic digestion is a process where biodegradable material is breakdown through microbes in the absence of oxygen. Special reactors are used for digestion process and controlled specific conditions are provided inside reactors such as pH, moisture content and temperature etc. The purpose of these conditions is to provide favorable environment to microbes and allow them to increase their number and to enhance the degradation process to produce methane (FCM, 2004).

The organic fraction may contain yard waste, paper waste, food waste and any other type of organic matter. The anaerobic digestion process is highly successful if the wastes are containing high quantity of organics, primarily this process produces methane (CH_4) and carbon monoxide (CO) and also with small fraction of other gas gases such as H2S (Tatamiuk, 2007).

Anaerobic digestion basically consists of three steps. In first step, organic material is prepared through sorting, segregation and size reduction. In second step, favorable environmental conditions are provided to ensure digestion process through microbes such as pH up to 6.7 and maintain temperature about 55-60 degree centigrade. These components are well mixed for approximately 5-10 days, but in colder climate slurry is mixed at low temperature for long time. In third step, the residual sludge is disposed of, if it is contaminated, after treatment it is disposed of and it is an extra step. The microbes which have vital role are classified into two groups: one is the acid forming and second CH_4 forming group. Acid forming group is used to treat complex organic components into simple acids and the CH_4 forming bacterial group convert simple acids into CH_4. The CH_4 forming bacterial group is sensitive to different environmental factors; temperature is the core component, control of oxygen and also preventing from entrance of toxic substances into the system. Generation of CH_4 can take place in two ways, either it is collected directly off of the landfill sites i.e. bioreactor landfill or sanitary landfill or pre-treated refused digested in digesters. Digesters are dived into high solid and low solid digesters. Low solid digester is well established as compared to high solid digester but it requires high amount of H_2O added to waste (Tatamiuk, 2007).

Advantages

Anaerobic digestion requires low capital and operational costs compared to thermal technologies. Surplus energy can be recovered in the form of CH_4 and also revenue generated through its sale. Pollution control is possible through appropriate control technology. Anaerobic digestion diverts most of organic components from landfills and also reduces risk of gas and leachate production. Well maintained and controlled system ensures low level of environmental pollution (Gruner, 2007). After anaerobic digestion of waste, the waste can be aerobically treated and can get benefits in the form of produced gas and soil conditioner from process for energy production and soil amendment respectively (Tatamiuk, 2007).

Disadvantages

Anaerobic digestion has some implication in economics and in practical parameters. Anaerobic digestion technology works well on pre-treated waste, like mixing of plastic with organic fraction may cause operational problems. Some anaerobic digestion facilities have ability to deal with mixed solid waste. Bad odor is produced during handling of material. Market value of end product may be lower because of the presence of toxic contaminants in it as it is difficult to get rid of them during processing. Anaerobic digestion has high cost for handling, storage, and processing (Gruner, 2007). Generally this process is used for the sewage and manure treatment because of their homogeneous in nature and also easy for microbes to degrade them. Mixing of these components with solid waste would enhance the microbial activity to degrade it (Tatamiuk, 2007).

2.5.2 Incineration

Incineration is also known as combustion (Tatamiuk, 2007) and thermal treatment of raw waste feed into the system (Zaman, 2010). Only the organic fraction such as plastic, combustible and putrescible are burnt in the system and as a result of which gases and residues are produced (Tatamiuk, 2007). According to Zaman, (2010) end-product consists of carbon dioxide (CO_2), water (H_2O), incinerated bottom ash and small quantity of residual carbon. The treatment process requires enough quantity of oxygen (O_2) to oxidize the waste, and the typical temperature at about 850ºC (Zaman, 2010). Incineration technology has the basic components, such as feeding chamber, combustion vessel, exhaust system and residual ash chamber. The feed stock should be well mixed, dried and heated for defined time period. Derived fuel systems, on-site commercial and industrial combustors, mass-fired combustors and modular combustor are the common incineration units in use (Tatamiuk, 2007).

Advantages

Thermal treatment has ability to reduce volume of waste and considerable amount of solid waste diverts from landfills (STANTEC, 2010). According to EPA (2004) the bottom ash from the system may have approximately 10% by volume and 20 to 35% by weight of original waste stream which is fed into the system. Thermal treatment facility has ability to recover energy, variety of chemicals and minerals could also be recovered and reused from waste stream. Incineration facilities have the ability to destroy number of toxic substances present in solid waste (STANTEC, 2010).

Disadvantages

Incineration of waste may contain heavy metals and there are also chances of dioxins in gases, ash and H_2O. Those communities living close to solid waste incineration facilities bear health problems and also a source of environmental pollution (EPA, 2004). These facilities having high capital and operational costs and are yet unproven technologies (Gruner, 2007).

Pyrolysis technology

In pyrolysis, thermal degradation of biomass waste take place in the absence of O_2. Pyrolysis and gasification depends on external source of heat. In case of pyrolysis, the conversion of organic matter to liquid, solid and gaseous components takes place through thermal cracking and condensation (STANTEC, 2010). The produced gases from pyrolysis processes are used as an alternative fuel which substitutes the natural gas, char and pyrolysis oils are also produced from it. Combustion process requires temperature at about 815ºC (Tatamiuk, 2007).

Both the pyrolysis and gasification systems having almost the same operations, these technologies convert waste stream to char, gases and liquids. However, a small amount of oxygen (O_2) or steam is required in the gasification process (STANTEC, 2010).

Advantages

Pyrolysis technology has ability to divert large quantity of waste stream from landfills. It can produce different types of products like fuel oil, gases and also recover recyclables at the front-end of technology (STANTEC, 2010).

Disadvantages

Pyrolysis technology has higher capital and operation costs (STANTEC, 2010). Products produced from pyrolysis are relatively less valuable (Tatamiuk, 2007).

Gasification technology

According to Tatamiuk (2007) gasification is a modified form of pyrolysis system, using small amount of O_2 which produces sufficient heat that enables the system to be self-sustained. Due to partial combustion of organic waste stream resulting in the production of fuel gas that contains H_2, CO and hydrocarbons. Vertical and horizontal fluidized bed combustion are the gasification types, which are very common in use (Tatamiuk, 2007).

There are basically three gasification technologies are in use: high temperature gasification system, fixed bed and fluidized bed combustion technologies, although high temperature gasification technology has commercial scale value (STANTEC, 2010).

Advantages

Gasification like pyrolysis have high tendency to reduce particulates and sulfur dioxide (SO_2) emissions from process (Zaman, 2010). The syngas (consists of CO, H_2 with little concentration of H_2O, CH_4, N2 and CO_2) produced from gasification system can be used to generate heat and electricity. This technology is basically formulated to produce and use of syngas from system (STANTEC, 2010). Gasification is not an incineration system but a combustion technology, where efficiently energy is recovered from the system. This technology is more attractive due to high production of energy (STANTEC, 2010).

Disadvantages

Gasification also has high capital and operational costs. It does not have ability to treat mixed municipal solid waste (MSW). The Gasification system has less ability to generate revenue from solid waste stream as compared to net investment costs (STANTEC, 2010).

Residue from gasification may be hazardous due to contaminants present in solid waste used as a feed stock for processing. Gasification is not proven technology for non-organic fractions of waste stream treatment. It is highly expensive than the approved facilities (STANTEC, 2010).

2.5.3 Landfill gas production and utilization

Anaerobic digestion of organic components from solid waste stream which are helpful for the production of landfill gas (Willumsen, 2009). Production of landfill gas from sanitary landfill facility is comparable with anaerobic digestion but make difference only at the operational control on sanitary landfill (Tatamiuk, 2007). From the total concentration of landfill gas, the CH_4 has 50% concentration level with 34 MJ/m^3 energy value (Willumsen, 2009).

The degradation of organic fraction in sanitary landfill subsists of following steps: aerobic, anaerobic (non- CH_4 production stage), anaerobic with CH_4 production build-up stage and at last anaerobic steady sate level. Recovery and utilization of landfill gas consists of four main steps such as recovery system, a pumping of gas process, a transmission of gas and a utilization of gas process (Tatamiuk, 2007).

Advantages

Appropriately capture of produced landfill gas from facility could be used as an alternative energy source and this method is also helpful in reduction of greenhouse gases (GHG) i.e. CH_4

and CO_2 emission (Willumsen, 2009). Therefore a CH_4 greenhouse gas is 21 times stronger than CO_2 greenhouse gases (SCS ENGINEERS, 2005).

Collection of gas contributes in reduction of fire hazards, odors and vegetation damage. If we compare landfill gas and anaerobic digestion systems, landfill gas requires less operational and maintenance costs. landfill gas is an important source of waste-to-energy and worldwide energy recovery projects on landfill sites are considerably increasing, approximately 10% growth rate per year since 1990 (Tatamiuk, 2007).

Disadvantages

Landfill gas basically associated with two pollutants as the emission of biogas and percolated leachate. Produce leachate could be prevented and extracted either through natural impermeable bottom layer or through man-made structures such as piping network under landfills. Capture and utilization of produced gas could also be possible from landfills (Karapidakis et al., 2010). Landfill gas utilization could be possible to generate revenue, if it is located nearby its consumers. About 60% plant cost is associated with turbines or generators, so either the consumers must be near to it or purchase power at a higher cost (Tatamiuk, 2007).

2.5.4 Bioreactor landfill

Bioreactor landfill is relatively new technology for the processing of solid waste stream. This technology depends on particular design and operational system which accelerates the degradation of solid waste such as green waste, food waste, paper and other type of organic wastes. It’s process is enhanced by adding optimum moisture content and enough micronutrients available for the organic matter degrading microbes. This technology has two important functions: one is the promotion of degradation of waste and second is reduction of time of waste stabilization. The steady levels of environmental performance parameters are the concept of landfill waste stabilization which includes the rate of landfill gas production, composition and concentration of leachate. The circulation of leachate in the system has an important role while degradation of organics in the system. The circulated leachate may contain some hazardous substances and also heavy metals (Warit, 2003).

Advantages

Bioreactor landfill rapidly stabilizes waste stream and reduces time to be burden on environment in terms source of pollution. It is also beneficial because avoids from settlement of new landfill sites by providing airspace. Revenue could be generated through enhancement of gas production. Bioreactor landfill technology has advanced leachate collection and storage system and reduces its cost and toxicity (Warith, 2003).

Disadvantages

Bioreactor landfill has high capital and operation costs as compared to sanitary landfills. This technology is not yet proven at commercial scale. It is also a major source of odor and increases instability of slope liners (Warith, 2003).

2.5.5 Other emerging waste-to-energy technologies

According to Kumar (2000) and Tatamiuk (2007) these are more technologies, which are not in common use yet but may become more attractive options in future, are precisely described below.

Pelletization

The process of producing fuel pellets from solid waste stream called pelletization. The complete process consists of drying, removal of non-combustibles, grinding and mixing steps. Pellets having higher calorific value as compared to raw garbage and also known as refused derived fuel. These pellets could be used and valuable for the production of energy (Kumar, 2000).

Plasma arc (pyro-plasma process)

Plasma arc technology uses plasma arc flame as a source of heat. This technology has ability to utilize organic and inorganic components of waste stream. At commercial level, a full pilot project is yet to be established (Kumar, 2000). This facility is proposed and cloud be used for hazardous waste treatment (Tatamiuk, 2007).

Garret flash pyrolysis process

A low temperature technology is used for the production of fuel oil. Coarser waste like organic components first shredded to reduce its size and convert to various fuel oils at about 500ºC (Kumar, 2000).

Fermentation process

Fermentation technology utilizes biological conversion technique to produce ethanol. Appropriate feedstock for this process is wood, agriculture residues, grasses and the organic fractions of municipal solid waste (Tatamiuk, 2007).

Refused derived fuel (RDF)

Refused derived fuel is a process where efficiently remove the inert fractions from waste and produces a uniform fuel that could be used in waste-to-energy plants and also in other thermoelectric plants as an alternative fuel source. During the processing of waste stream to refused derived fuel it could be possible to add calcium (Ca), which is helpful in reduction of hydrogen chloride emissions during combustion process (Themelis, 2002).

Fluidized bed combustion

Fluidized bed combustion technology only utilizes the combustible fractions, after the removal of inert substances from waste like glass and metals etc. The required feedstock is fed up on the top of a fluidized bed of sand or limestone. Typically, the temperate requires for this process is in the range of 830 to 910ºC and may can utilize more fuel if feedstock having high moisture content (Themelis, 2002).

3.0 Conceptual framework

The framework structure in Figure 3.1, deals with the solid waste management strategies. This waste management process mainly revolves around the socio-environmental, economic issues, technical analysis and political decision making factors. The planners/solid waste professionals have in-depth knowledge about the technical issues of different waste-to-energy recovery technologies and are able to carry-out technical analysis, they have the ability to provide correct information and advice to political leaders, who are the decision making bodies for the implementation of waste-to-energy facility. However, the selection of appropriate waste-to-energy recovery facility mainly depends on socio-economic and environmental factors.

In the binging, it is important to define the system boundaries, which will involve what types of the waste planning activities will be considered during the solid waste management practice i.e. waste minimization, segregation, recycling of products, and the remaining waste is available for energy recovery technologies, which can be utilized to produce "green energy" in the form of heat and electricity etc. respectively has complex process.

In the second step, the selection procedure depends on the available options i.e. waste-to-energy technologies, and generally given preferences to those technologies that is successfully operating locally, regionally and implemented worldwide. There must be criteria for selection of reasonable facilities according to local needs, mainly depends on a variety of important factors such as social, environmental, economic and technical issues. It is necessary to give more technical feedback on various technologies and local needs. The technical constrains play crucial role to predict the volume, type and quantity of generated solid waste which are suitable for specific type of waste-to-energy technology. The professionals or planners should carry out the monitoring and assessment of different types of available technologies by considering these important factors, and select the most efficient resource recovery options. These technologies could be either convectional or emerging facilities.

In the third step, through this strategy, each type of waste-to-energy recovery technology should be evaluated and ranked and then the recommendation should be forwarded to political decision makers.

In the final step, results forwarded to politician decision body for final approval, they may give their decision either in-line with professionals/experts opinions or according to their own wills for an implementation of waste-to-energy technology in study area.

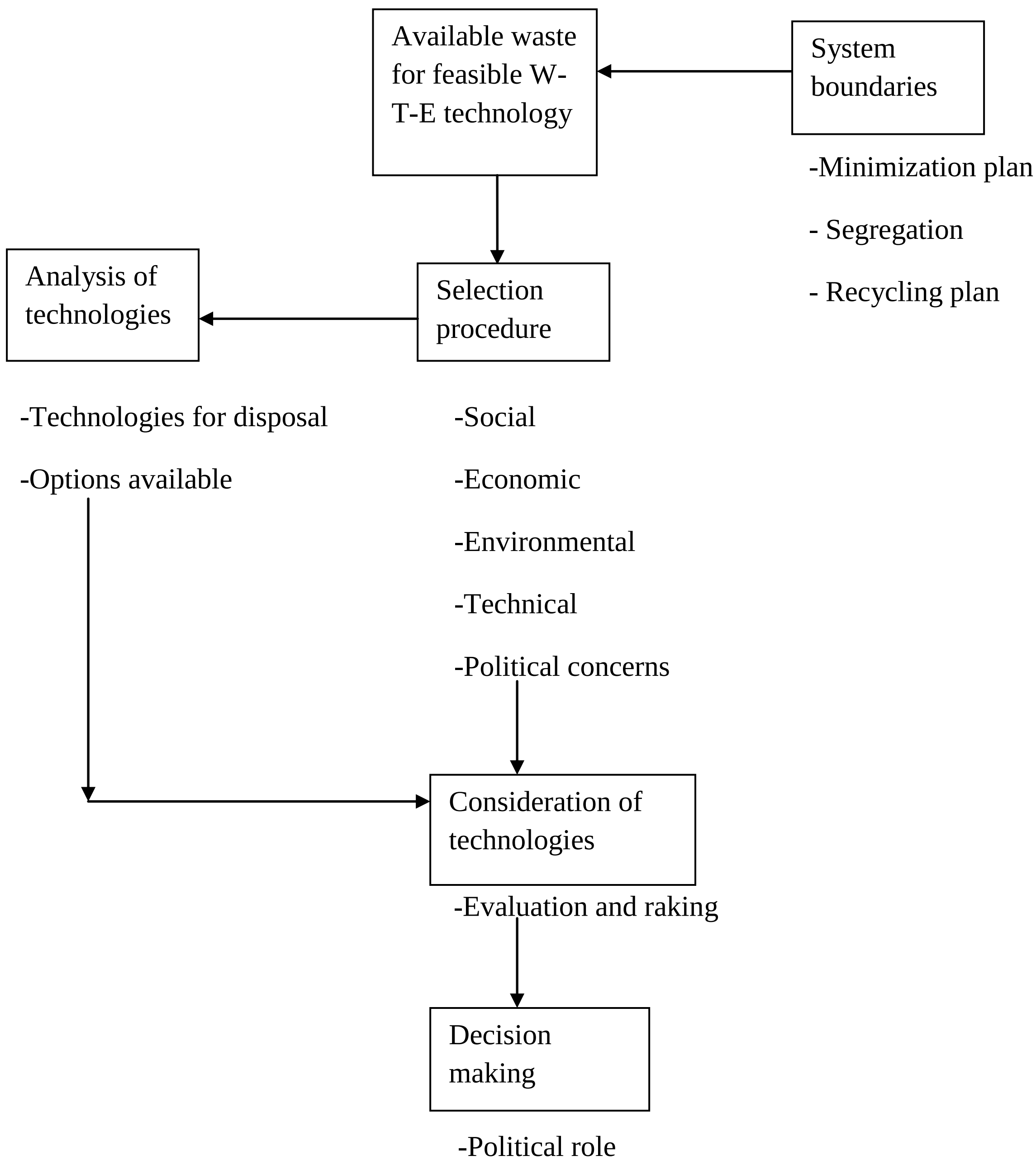


Figure 3.1: Decision framework for waste-to-energy recovery technology implementation.

This selection process or flow is more general and may differ in each case. In the real life political leaders have power and make their own decision for the implementation of facility either their decision is right or wrong.

There are different influencing factors (Figure 3.2) for the selection and finally implementation of feasible waste-to-energy recovery technology like environmental, economic, social, technical and political factors. These factors may have different importance or values according to different country rules and regulation and also depends on the local area requirements. After in-depth analysis of each facility at the end if most feasible technology is selected and successfully implemented may generate numerous befits in the form of job creation, resource conservation, reduce environmental impacts, source of renewable energy, low cost energy, land preservation and lower health impacts etc.

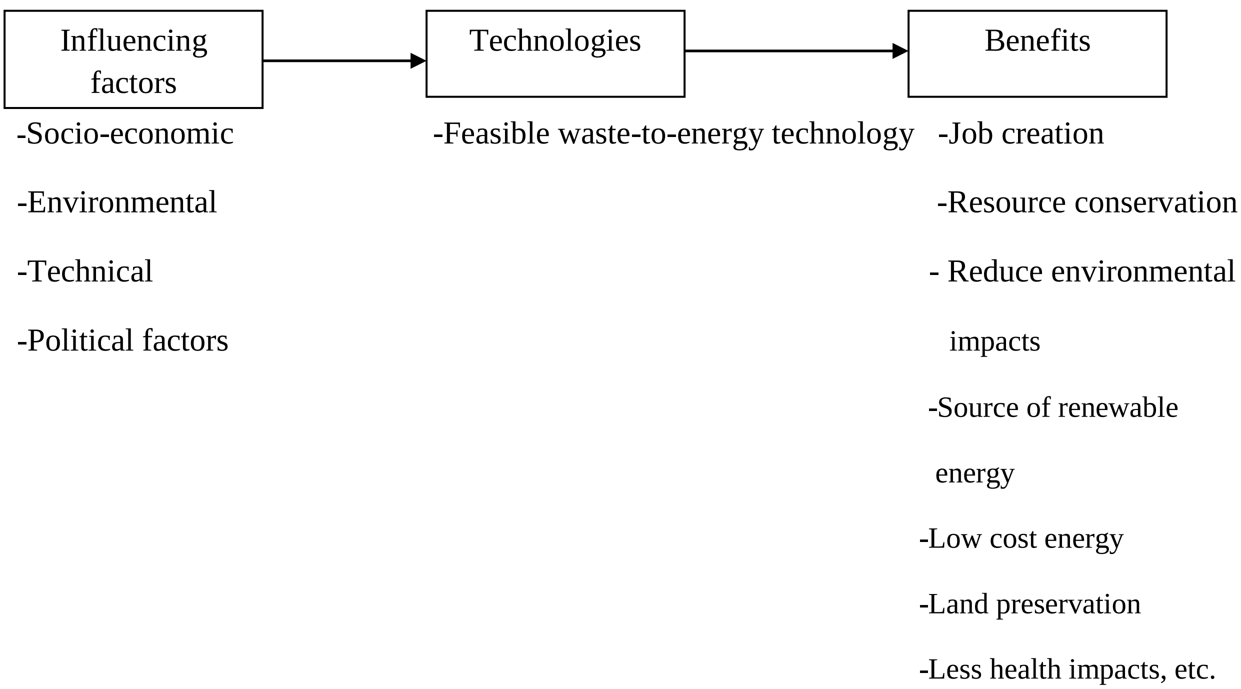


Figure 3.2: Possible benefits from the best selection of waste-to-energy recovery technology.

4.0 Materials and methods

4.1 Description of the study area

Lahore is the capital and the largest city of the Punjab. The total area under this city is roughly 1772 square kilometres; with a population of about 8 millions (Joeng et al., 2007). It is situated beside river Ravi and borders of India. It is subdivided into six towns for its management perspectives like, Shalamar Town and Nishtar Town (representing rich communities), Ravi Town and Iqbal Town (representing middle income communities), and Data Town and Aziz Bhatti Town (belonging to poor communities) (Naveed et al., 2009). But according to Joeng et al., (2007), Lahore is subdivided into main 9 towns, i.e., Iqbal, Gulberg, Samanabad, Data, Ravi, Shalamar, Aziz Bhatti, Wahga and Nishtar town (Fig. 4.1).

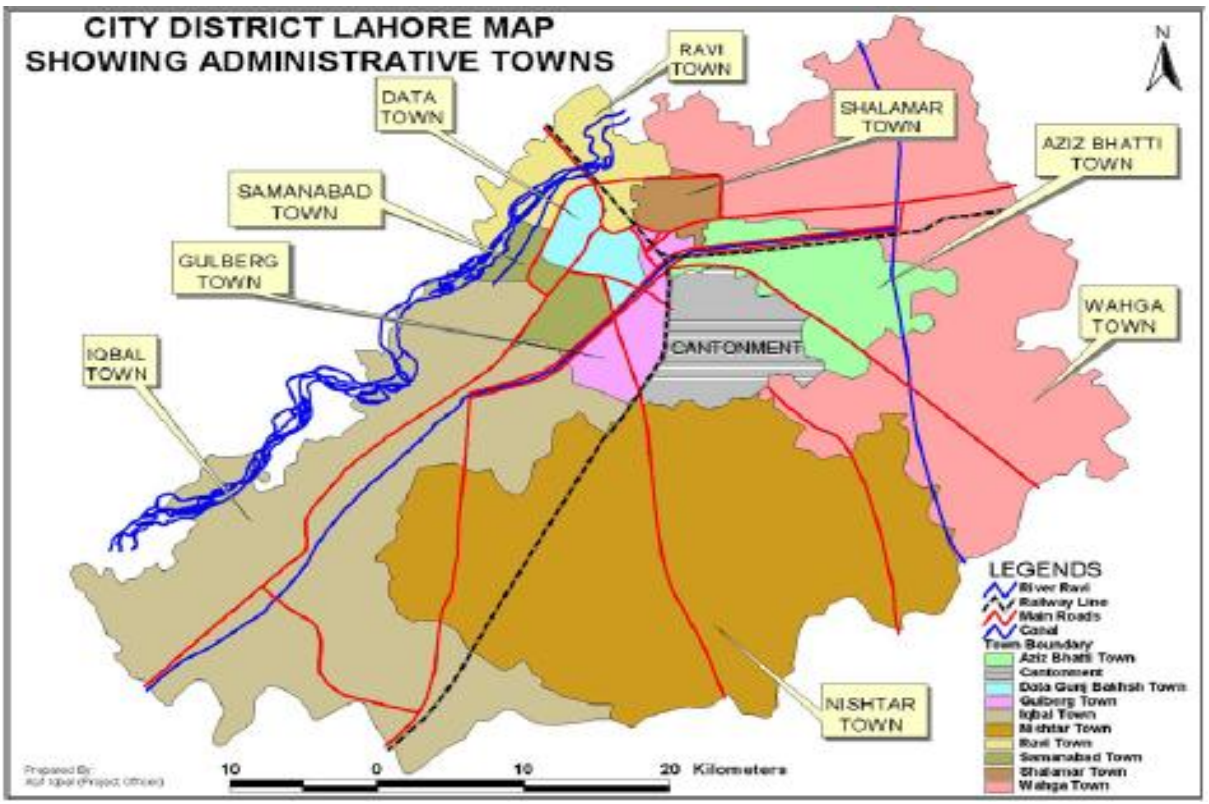


Figure 4.1: Local map for study area (Imtiaz and Ali, 2008).

The city is the centre of commerce, finance and transportation and is well known for its industries and their production systems such as steel manufacturing, shoe making, rubber production and traditional metal craft. Wheat and cotton are the major crops production, whereas rice, sugarcane and millet are minor crops (Joeng et al., 2007). According to Batool et al., (2009) temperature in Lahore raises maximum to 40°C in summer and goes down to nearly 2°C during winter. The average rainfall is 628.8 mm per year is measured over the period of 30 years.

4.2 Methodology

The research work is based on primary and secondary data collection in order to respond to the research questions of the study. The secondary data were collected directly from concerned offices, research institutions like universities and NGOs, which are closely dealing with the solid waste management issues. After reviewing their reports, the primary data were also collected on the basic issues, which are not dealing with, or not clearly mentioned in reports through "key informed consent approach". The secondary data come from a combination of electronic and printed form of materials such as published books, research papers, journals and articles etc. Primary and secondary data consist of composition and quantity of solid waste, socio-economic and environmental related issues of solid waste stream and also about waste-to-energy recovery technologies.

4.2.1 Methods for data collection

The following methods were adopted for the collection of required data,

- Detailed study of yearly solid waste reports of concerned institutions.
- Key informant interview with solid waste management staff.
- Review of already published literature.
- Personally make visit in the city and to the waste disposal sites to assess the solid waste management system.

4.2.2 Primary data collection

The qualitative data have been collected through focus group interview from relevant top management of Lahore Waste Management Company. The following questions were treated:

Question 1: Do you consider different sectors or towns for the solid waste collection in Lahore?

Question 2: What are the current collection and segregation methods at sources?

Question 3: Do you have any planning to find out recent solid waste composition? How and this waste composition will be either based on sectors or towns level?

Question 4: Is there any waste-to-energy recovery technology is operating in Lahore? If yes which type of technology is implemented?

Question 5: If no then, are you thinking about the implementation of any waste-to-energy recovery technology in Lahore?

Question 6: What do you think, if waste to energy recovery technology implemented in Lahore, how much quantity of waste will be handled and what types of positive impacts will generate?

Question 7: According to your knowledge, which type of energy recovery technology is the most beneficial and suitable based on current solid waste composition and quantity of Lahore?

Question 8: What are the most important influencing factors while selection of waste-to-energy recovery technology in case of Lahore and in general as well?

Question 9: At what extent economic factor is important while selection of technology?

Question 10: Political decision makers will have their own decisions regarding waste to energy technology selection or they will follow and consult with experts or relevant professionals?

Question 11: Do you have any planning to construct sanitary landfill sites in Lahore?

Question 12: What types of socio-economic-environmental issues specifically related to Lahore solid waste?

Question 13: What types of health impacts on the workers and associated societies of produced solid waste in Lahore?

4.2.3 Data analysis

The statistical analyses were carried out on waste composition, quantity and population density variables and results are drawn in the form of percentage, mean, range and standard deviation. In regression analysis, 0.05 significance level is used. Data are presented in tables and diagrams (pie diagrams, bar diagrams). The secondary data on costs of the waste-to-energy recovery facilities is analyzed and compare on the basis of cost/ton of waste processing in different technologies.

4.3 Research ethics

Ethical issues were considered during the research work. These revolved around those people that were an integral part of the research process. It was necessary to consider ethical consideration in such kind of research work, as research was carried out by direct interaction with government departments, NGOs and different related people for the data collection. The relevant persons for the required data collection were informed about the aims of the study and their participation will be volunteer.

5.0 Results and discussion

5.1 Quantity and composition of generated waste

The quantity and composition of waste has important value for the selection of different energy recovery technologies. The quantity of waste stream relatively has more importance for waste-to-energy recovery technology compared to composition because without sufficient amount of waste it becomes difficult to recover capital cost and also to maintain and operate a waste-to-energy technology in a cost effective manner (Tatarniuk, 2007). The amount of generated waste from different 9 towns of Lahore is estimated by multiplying the used 0.65 and 0.7 same common factors with increasing population trends of each town in 2007 and 2010 respectively. The estimated total amount of waste was 5186 tons per day in 2007 (Imtiaz, 2008), and in 2010 this estimated waste was 5672 tons/day (Lahore Waste Management Company, 2010), which is summarized in Table 5.1.

According to conducted interviews with the top management of relevant district solid waste management company, Lahore is divided into towns and not into sectors for the proper solid waste management. Currently there are no source segregation methods being practiced in Lahore. The city is planning to develop a detailed waste composition and characterization study based on different seasons and income levels.

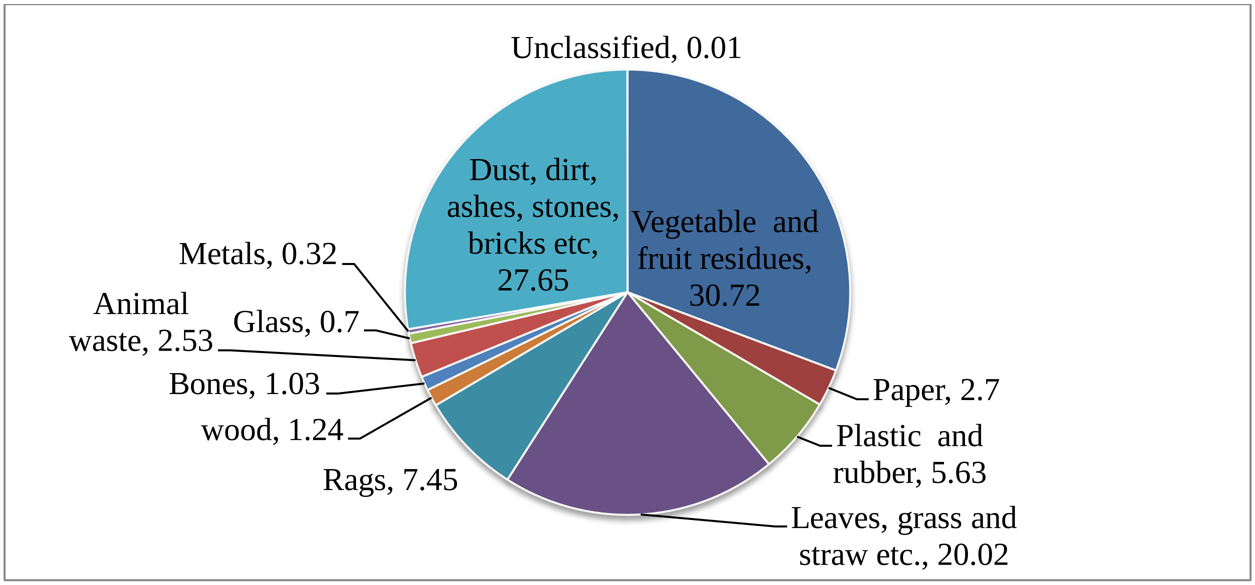
According to Imtiaz (2008), the estimated Lahore solid waste compositions by YCHR-Centre for Research and Training and Lahore Solid Waste Management Department for 2004 and 2008 years respectively are not for the individual town but as a whole city. The composition of generated solid waste in Lahore remained same for both 2004 and 2008 years (Imtiaz, 2008). The composition of generated waste for 2010 is not yet determined and it is estimated by looking at the previous year’s increasing trends in composition of waste. This is also the same in composition like all past years but the total increase in quantity of waste has occurred over the period of time.

Table 5.1: Solid waste generation in tons per day from different 9 towns of Lahore in 2007 (Imtiaz, 2008) and 2010 (Lahore Waste Management Company, 2010).

Towns	**Population 2007**	**Estimated waste generation in 2007 (ton/day)**	**Population 2010**	**Estimated waste generation in 2010 (ton/day)**
Samanabad town	1001215	651	1017524	712
Gulberg town	791709	515	804606	563
Aziz Bhatti town	682332	444	693447	485
Data town	986874	641	1002950	702
Iqbal town	998379	649	1014642	710
Nishtar town	956154	622	971729	680
Ravi town	1024944	666	1039103	727
Shalimar town	899156	565	883314	618
Wagha town	667395	434	678267	475
Total	**8008158**	**5187**	**8105582**	**5672**

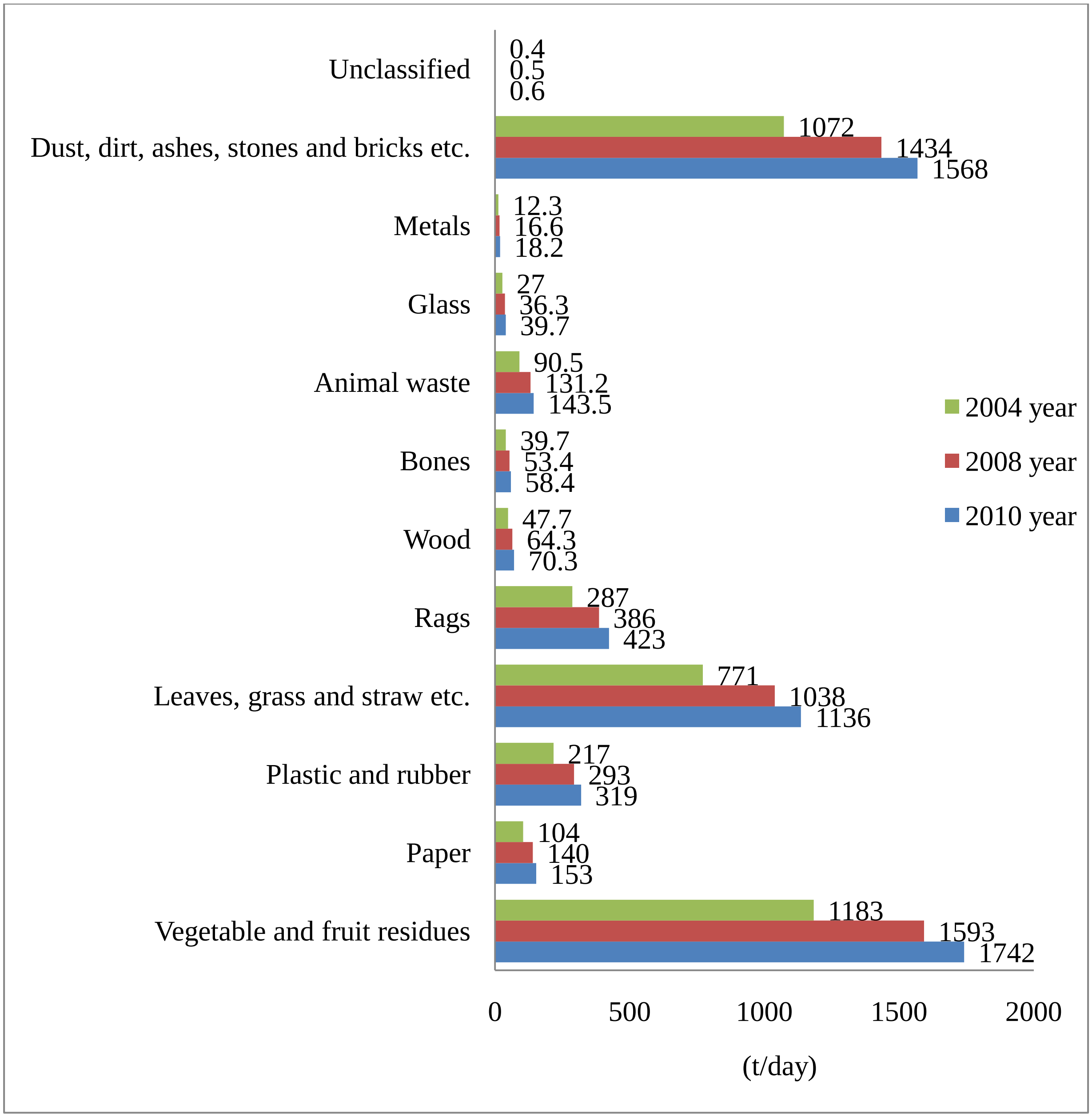
Waste composition in Lahore is summarized in Figure 5.1. The pie chart shows that vegetable and fruit (31%), dust, dirt, ashes and bricks (28%) and leaves, grasses and straw (20%) contribute the highest proportion, respectively. But the overall organic components (approx. 67%) of the solid waste stream have the highest proportion. The inert components (28%) of solid waste stand alone at 2nd largest waste constituent. The recyclables (7%) make up the lowest proportion of the total waste stream.

Figure 5.1: Estimated average composition of solid waste in % for 2004 (YCHR-Centre for Research and Training by Imtiaz, 2008), 2008 (Lahore Solid Waste Management Department by Imtiaz, 2008) and 2010 (Lahore Waste Management Company, 2010).



In Figure 5.2, compare the estimated quantity of solid waste in tons per day among three years i.e. 2004, 2008 and 2010. When we compare the different fractions of Lahore solid waste, it can be seen that the quantity of waste is increased over time. However each component of waste increased in quantity with same ratio. Vegetable and fruit residues make the highest quantity over 6 years time period. Similarly the same case happened with leaves, grass and straw and dust, dirt, ash, stones and bricks fall on the second and third highest levels respectively. The glass, metals and unclassified components make the least quantity of waste stream respectively. There is a dramatic increase in total organics over past six years time period i.e. organic waste 2522 tons/day, 3407 tons/day and 3726 tons/day for 2004, 2008 and 2010 years respectively. Similarly the same case happened with inert components (i.e. increase from 1072 tons/day in 2004 to 1568 tons/day in 2010 year) of waste stream over this time period, having enormous quantity but with no value for either as recyclable or energy recovery. Recyclables are in low quantity but may play a major role by getting some revenue, can be helpful by reducing the total waste volume and also reducing burden on extraction of natural resources. However, recyclables increased from 256 tons/day in 2004 to 377 tons/day in 2010 year.

Figure 5.2: Estimated solid waste composition in tones per day in 2004 (YCHR-Centre for Research and Training by Imtiaz, 2008), 2008 (Lahore Solid Waste Management Department by Imtiaz, 2008) and 2010 (Lahore Waste Management Company, 2010).



5.2 Effects of economic conditions and population trends of communities on solid waste generation rate

Several factors have significant influence in municipal solid waste production like increase in population number, economic development, climate, consumption pattern, culture and institutional structure (Yousuf, 2007). From these factors, the economic development and increase in urban population are the core factors that cause enhanced consumption rates and increased waste production in developing countries (Yousuf, 2007). This can be seen in case of Lahore as well, where estimated per capita waste increased from 0.65 in 2007 to 0.70 in 2010. Economic development and population growth as mentioned in Yousuf (2007) are likely to be the main factors determining the increase in waste in Lahore. It is reported by Naveed et al., (2009); only six towns out of nine in Lahore are categorized into different economic groups, which are summarized in Table 5.2 and 5.3, whereas the rest three towns are not yet classified.

According to Lahore Waste Management Company (LWMC) (2010), they studied only the Mahmood Booti site among the available three waste disposal sites, to find out waste generation. Where, almost half of the solid waste is dumped per day. LWMC estimated the same common factor for each year as 0.65 kg/capita/day for 2007 and 0.7 kg/capita/day for 2010, can be seen in Tables 5.2 and 5.3. The estimated common factors of waste production from this site was generalized over the whole Lahore city to estimate the waste production by multiplying with annual population growth, without considering the different income levels of groups that produces varying per capita per day waste as in the case of Dhaka city in Table 5.4. The solid waste which is coming to Mahood Booti disposal site is mainly from four towns i.e. Gulberg, Data, Shalamar and Aziz Bhatti towns and partially from the rest of five towns.

With the increase of income, the production of solid waste also increases in developing countries in contrast to developed nations (Liu, 2010). Solid waste production per capita per day increased with economic development from low income earning to high income earning communities in Dhaka city (Yousuf, 2007), that can be seen in Table. 5.4, i.e., 0.513 for high income group, 0.400 for middle income group, 0.313 for middle-low income group, 0.336 for low income group and 0.260 for lowest income group.

Unfortunately, the data are not precise enough in case of Lahore to explain it, as it is in case of Dhaka, because increase of common factor from 0.65 in 2007 to 0.70 in 2010 shows no linkage with economic development. The type of technique used by Lahore Waste Management Company to estimate the solid waste generation may produce the haphazard results and cannot precisely estimate the waste composition and quantity from different income level groups. These are the most important factors for the selection and design of suitable waste-to-energy recovery technology, which are missing in case of Lahore.

Table 5.2: Relationship of economic conditions of different communities with per capita waste production in 2007.

Communities economic characteristics		**Population**	**Waste (ton/day)**	**Waste (kg/capita/day)**
(Naveed et al., 2009)		(Imtiaz, 2008)		(Self reported)
Rich	Shalimar town	869156	565	0.65
	Nishtar town	956154	622	0.65
Moderate	Ravi town	1024944	666	0.65
	Iqbal town	998379	649	0.65
Poor	Data town	986874	641	0.65
	Aziz Bhatti town	682332	444	0.65

Table 5.3: Relationship of economic conditions of different communities with per capita waste production in 2010.

Communities economic characteristics		**Population**	**Waste (ton/day)**	**Waste (kg/capita/day)**
(Naveed et al., 2009)		(Lahore Waste Management Company, 2010)		(Self reported)
Rich	Shalimar town	883314	618	0.7
	Nishtar town	971729	680	0.7
Moderate	Ravi town	1039103	727	0.7
	Iqbal town	1014642	710	0.7
Poor	Data town	1002950	702	0.7
	Aziz Bhatti town	693447	485	0.7

Table 5.4: Different income level groups and per unit waste generation rate in Dhaka city (Yousuf, 2007).

Domestic waste (kg/person/day)	**Income level (**Tk/month/family)	**Domestic waste** (kg/person/day)		
		Dry season	**Wet season**	**Average**
High income group	20,000≤	0.588	0.438	0.513
Middle income group	10,000≤X<20,000	0.371	0.428	0.400
Middle-low income group	5,000≤X<10,000	0.279	0.346	0.313
Low income group	3,000≤X<5,000	0.326	0.345	0.336
Lowest income group	<3000	0.314	0.205	0.260

It is mentioned in literature that the generation of solid waste is directly proportional to population growth (Yousuf, 2007). But in case of Lahore, the effect of population growth on waste production is not well determined by Lahore Waste Management Company (LWMC), as it is already mentioned in previous paragraph, LWMC studied only the Mahmood Booti site among the available three waste disposal sites to find out same common factor for both years for waste generation per day and generalized it over whole city to estimate overall waste production. The estimated waste has been calculated by multiplying the population growth by increasing constant factor from 0.65 in 2007 to 0.70 in 2010, and can be seen in Table 5.1.

From descriptive statistics, it is known that the mean population of each town was 886000 in 2007 which increased to 900000 mean populations in 2010. The standard deviation changed from 91.6 to 99.9 for 2007 and 2010 respectively and this makes sure that from individual town in Lahore, population growth has been recorded. The increase of 147573 tons of waste in total quantity of solid waste and addition of 127000 population numbers in total population occurred from last four years time period i.e. 2007 to 2010. The increase in population growth and waste production per year, over period of four years can be seen in Table 5.5.

Table 5.5: Per year increase in population growth and waste production from 2007 (Imtiaz, 2008) till 2010 (Lahore Waste Management Company).

Towns	Population increase per year	Waste increase per year (ton/day)
Samanabad town	4077	15.25
Gulberg town	3224	12
Aziz Bhatti town	2779	10.25
Data town	4019	15.25
Iqbal town	4066	15.25
Nishtar town	3894	14.5
Ravi town	3540	15.25
Shalimar town	3540	13.25
Wagha town	2718	10.25

5.3 Socio-economic and environmental conditions in the absence and presence of waste-to-energy recovery technologies

According to conducted interviews with the top management of relevant district solid waste management department, there isn’t yet any waste-to-energy technology implemented in Lahore. Lahore solid waste management department thinking about to establish a waste-to-energy recovery technology but required a detail feasibility study to analyze that whether the type of waste and waste practices are suitable for waste technologies or not. They also did not give much importance to the types of socio-economic and environmental issues specifically related to Lahore solid waste management. However, below it is try to asses these socio-economic and environmental impacts worldwide which are associated with solid waste in the presence and absence of waste-to-energy technologies.

5.3.1 Reasons for the absence of waste-to-energy technologies

According to conducted interviews from the top management of relevant district solid waste management department, it is anticipated that the existing solid waste management system is a source of health and environmental concerns for the citizens because of; no containment of municipal solid waste, low waste collection rate, haphazard waste disposal, occupational health and safety concerns and low managerial and technical skills of existing staff etc.

A. Environmental and health impacts

Potential environmental and health impacts are generated due to inappropriate handling, design, operation and maintenance of disposal sites. These inadequate waste management practices lead to transmission of diseases or may also threaten local people’s health. Decomposable organics are the major source of health risks as they provide suitable breeding grounds for disease vectors like flies, mosquitoes and rats etc. Those who closely deal with solid waste like waste pickers and handler are more susceptible to diseases and may also act as a transmitter of these diseases, especially when they are engaged with the handling of animal or human or hazardous waste mixed with solid municipal waste stream. Other nearby community members are also at high risk for facing serious problems such as birth defects, cancer, poisoning and other diseases (LAC, 2001).

Water contamination

Contamination of surface and ground water occurs when it is mixed with dumped solid waste leachate containing different types of pathogens and toxic substances in it (LAC, 2001).

Air pollution and Greenhouse gas (GHG) production

After the disposal of solid waste stream in dumping site, degradation of organic fractions due to anaerobic process results in the production of CH_4 green house gas which is stronger than CO_2. Often the collected waste in streets or in dumping sites is openly burnt aiming to reduce its volume which become a source of carbon monoxide, nitrogen oxide and soot that are harmful for human health and also a source of air pollution. Lethal gases i.e. carcinogenic dioxins are produced by burning of polyvinyl chlorides (LAC, 2001).

Ecosystem disturbance

Dumping of solid waste in streams and rivers could produce alarming situation for both aquatic and terrestrial flora and fauna. Eutrophication conditions are produced due to high concentration of nutrients flow from waste stream into water body and some of heavy solids settle down and changes water flow pattern and also its bottom habitat. Development of waste disposal site in fragile ecosystems may have adverse affect on important natural resources and its services (LAC, 2001).

Local flooding and property value

Heaps of waste streams in streets may clog drains and create flooding situation. Presence of dumping or landfill sites near the residential areas may injure the local inhabitants and destroy property (LAC, 2001).

B. Social Impacts

The social impacts faced by community related to solid waste can be categorized into following groups like direct, indirect impacts and also transport related problems.

Direct impacts

Some direct social impacts are raised from the garbage such as spreading of bad smell during transportation of waste, facilitation of breeding grounds for disease vectors due to the fallen garbage along roads during transportation and sitting landfill sites, reduction of the property value and production of unpleasant odor from landfill sites (Bandara et al., 2003).

Indirect impacts

Some indirect social impacts are also faced by community from garbage such as increased frequency of floods during rainy season, improper personal safety raised during smoke and production of toxic gases from open burning of garbage, more vulnerability of children to diseases raised from improper solid waste disposal like skin diseases etc. (Bandara et al., 2003).

Transport related social issues

The transport related social issues include road traffic congestion through solid waste transfer vehicles, aesthetic nuisance from improper cover of garbage bags on trucks may fall from trucks during its transportation along main roads, dust pollution and deterioration of roads due to heavy transportation which results an increase in the maintenance cost (Bandara et al., 2003).

C. Economical issues

According to Lal et al., (2006) cost associated with poor waste management can be defined as "the direct and indirect cost associated with the current level of waste management that could be avoided if better management services were provided." Currently implemented waste management level and efficiency of the system defines the economic cost and the direct impacts of waste including the quantity of recycling of recyclable components from waste, linkage among waste and its impacts on aesthetic values, health and environment. The indirect impacts of waste management cover the impacts on fisheries yield, tourism and local economy. The cost associated with these impacts may be borne by individual or government or whole society.

Economic cost associated with waste stream could be estimated through with and without benefit cost analysis (BCA) which can be define as the difference between the economic net benefits of present waste management system (with waste condition) and the economic net benefits with improved waste management system (without waste condition). This analysis may be effective with and without analysis of cost and can also be reduced to an analysis of economic cost with waste with and without improvement in waste management (Lal et al., 2006).

The cost associated with and without improvement in waste management system varies dramatically. With improved waste management scenario, cost associated with waste impacts reduces. In case of with waste conditions, the direct economic cost of waste impacts includes the cost of poor human health due to improper waste management system. It covers the hospital cost, private doctors cost in terms of fees, medicine cost, importance of human life-in case of death, or its cost of suffering. The direct cost is associated with taking preventive measures to control different factors that may cause the human health impacts and also the loss of cost from recyclables which are directly dump into the disposal site. The indirect economic cost of improper waste management includes the loss fisheries, reduction in tourism earning and loss of aesthetic values (Lal et al., 2006).

5.3.2 Conditions for the presence of waste-to-energy technologies

A. Environmental impacts

Odor

Waste-to-energy facilities are designed to stabilize the waste. During the combustion process, source of odor emitting materials are completely destroyed and converted into slag and ash. The odor is mostly emitted during waste sorting and handling process. The odor emitted into the environment during unloading activities and from storage pits can be reduced by enclosed feeding hoppers of the combustion system and draft (i.e. negative air pressure) condition of unloading area (Weinstein, 2006).

Noise

Noise could be a source of pollution when waste transporting vehicles enters and comes out of the of the waste-to-energy facility. The noise pollution produced from waste transporting vehicles could be reduced by regular maintenance and responsible use of these vehicles. Certain hours of the day and specific routes for waste transportation are also other factors to reduce garneted noise from trucks (Weinstein, 2006).

Air pollution

Combustion systems from the waste-to-energy facilities are the main source of chemicals emission to the atmosphere. These emissions include dioxins, mercury, particulate matter and hydrochloric acid etc. However, these emissions are enormously reduced to minimum level through reduction of toxic containing substance, improvement in combustion facilities and use of gaseous control systems etc. (Weinstein, 2006).

Diesel emission reduction

Mostly the energy recovery facilities require small area for establishment relative to landfill and are built near the municipalities. This will eventually not only reduce time by shortening the distance but also emissions from diesel engines. Diesel engines of waste transporting vehicles are the major source of emission of NOx, particulate matters and hydrocarbons etc. These gases contribute in ground level ozone formation but this threat also reduces with reduction of travelling distance (Weinstein, 2006).

Greenhouse gases and clean energy production

Waste-to-energy facilities contribute in the production of renewable energy from solid waste stream and make less dependent on non-renewable energy resources (Weinstein, 2006). So the material left over after the segregation of recyclables and organics for composting came from renewable sources, this derived component of waste stream could be used as clean, sustainable and renewable fuel for heat and electricity production. It has been made confirmed by many independent studies that waste-to-energy facilities have capacity to generate electricity and avoid the greenhouse gases emissions and are more effective than landfills (Psomopolos et al., 2009).

B. Economic impacts

Real estate value

Uncontrolled dumping sites for waste disposal have opposition from local residence or communities because of its negative impacts on the real estate price. However, implementation of waste-to-energy facilities not only improved the local area condition but also increased its value. It is better to select a site for new waste-to-energy treatment plant where an old transfer station or industry can be built aiming to improve previous environmental conditions of that site (Weinstein, 2006).

Land requirement

Well maintained waste-to-energy facilities can operate more than 30 years. The waste-to-energy facilities require specific land area according to their size during their establishment. These can be expanded over more area by increasing their solid waste handling capacities. These energy facilities do not need periodic cost for more land. It is important that waste-to-energy facilities need significantly small land area as compared to landfills for handling of same quantity of waste (Psomopolos et al., 2009).

Employment

The construction of new waste-to-energy facility generates new job opportunities during its construction and operation phase as well. This may helpful for local people to improve their livelihood Social situations (Weinstein, 2006).

C. Social impacts

Land use

The implementation of waste-to-energy facilities faces the opposition and protest from local people or neighbors for its construction due to reduction of land value and production of bad odor from waste. So it is better to install new waste-to-energy plant on old and out dated industry sites to improve local conditions (Weinstein, 2006).

Aesthetic value

Proper design and implementation of waste-to-energy facility and improved landscape site are helpful in improving the aesthetic value of an area. However, proper design of facility and selection of site can the perception of local people for its implementation. The emitted gases or smoke from chimneys having negative impact could be reduced or eliminated by installation of control equipments (Weinstein, 2006).

Traffic

The installation of new waste-to-energy plant will require more waste on regular basis for its feeding, ultimately the increase in numbers of garbage vehicles will occur its surrounding. Traffic congestion on roads and its surrounding can be controlled through proper management like fixed hours in a day and also through special designed corridors for garbage vehicles (Weinstein, 2006).

5.4 Socio-environmental impacts of technologies

The different types of waste treatment technologies have different environmental and social acceptance levels as a "green energy" production and utilization. Some of these issues are described below.

5.4.1 Environmental impacts of anaerobic digestion

The anaerobic digestion process has the lowest environmental impacts. The organic fraction of waste is digested through microbial activity in oxygen deficient environment and this result in the production of bio-gas (mixture of CH_4 and CO_2) which is used as a renewable energy source. The sludge (leftover from digestion process) is nutrient-rich and can be used as manure (Varma, 2009). The major environmental advantage of this process is that it is CO_2 neutral process from waste reduction and has the lowest emission of CH_4 as compared to landfill (Gruner, 2007).

5.4.2 Social impacts of anaerobic digestion

Public perceptions about anaerobic digestion facilities are almost same as in case of incineration. It is advantageous of being not an incineration process. It is less noticeable as compared to incineration facilities, but still the acceptance of facility location can be negotiated with local community. Generally the anaerobic digestion plants should be located at a reasonable distance from community to avoid odor and noise pollution (Gruner, 2007).

5.4.3 Environmental impacts of thermal technologies

The thermal treatment facilities, especially the incineration process is the main source of particulate matter and other toxic gaseous emission like SOx, NOx, dioxin, and furan etc. into the environment, which are the major factors for escalating toxicity in ecosystems. The residual ash from the boiler could also be toxic. The additional pollution control equipment cost is about 30% of the total plant cost (Varma, 2009).

Rotary kiln

Due to short residence time for the combustion of waste stream, facility does not completely combust the waste and produces a large amount of ash which goes back again into the environment. The high operating temperature of facility is disadvantageous because it periodically causes leakage of kiln and is a source of air pollution (FCM, 2004).

Mass burn

In mass burn there is relatively more residence time for waste combustion and produces fine ash. It is also a source of air pollution (FCM, 2004).

Starved air incineration

This facility produces good quality of ash with small amount of particulate emissions as compared to above incineration technologies. The main drawback of this technology is the absence of emission control equipments for mercury, heavy metals and trace organics (i.e. chloro-benzene, dioxins, chlorophenol) in commercial scale facilities (FCM, 2004).

Fluidized bed combustion

The pre-processing of waste used in this technology produces better quality of ash (i.e. smaller amount of carbon contents). However, this technology is a major source of air pollution as compared to other mentioned technologies and requires more expensive air emission control systems (FCM, 2004).

Refused derived fuel

The direct environmental advantage of refused derived fuel is the pre-processing of waste stream into refused derived fuel and helpful in reduction of greenhouse gases and the indirect environmental befit is the replacing of fossil fuel combustion (FCM, 2004).

Gasification and pyrolysis

Gasification and pyrolysis are very attractive options for treatment of MSW, because these facilities have ability to reduce and avoid alkali and heavy metal emissions and also helpful in net reduction of SO_2 and particulate matter emissions. But the emissions of dioxins, volatile organic compounds (VOCs) and NOx are bit similar with the other thermal solid waste treatment options (Zaman, 2010).

5.4.4 Social impacts of incineration technologies

Communities rarely accept the incineration facilities for management of solid waste stream because of strong opposition from the local residents due to their concern about sewer health and environmental effects. Public awareness and information is therefore important while constructing a waste-to-energy facility like incineration (Gruner, 2007).

5.4.5 Environmental impacts of landfill gas production and utilization

Produced landfill gas is not only utilized for the energy production to cope with energy crises but also helpful in reduction of environmental damage and greenhouse gases emission impacts (Karapidakis et al., 2010). Often some of the environmental impacts are associated with landfill such as groundwater and surface waster pollution, odors, greenhouse gases emissions, air quality and ecological effects etc. These environmental impacts could be reduced thoroughly engineered landfills (FCM, 2004).

5.4.6 Social impacts of a landfill gas production and utilization

It is given preference that landfill sites should be closed to solid waste generated communities by taking consideration of easy transport of waste with minimal cost, but the communities have opposition to landfills to be closed to the housing. This results in difficulty to find out more appropriate site for landfill setting. Additionally, the construction of landfill site is very costly and having a limited time span. To maximize the efforts to minimize the total amount of waste disposal in landfills that make assure available free space over long period of time for waste disposal (Holroyd City, 2010).

5.5 Evaluation of socio-environmental impacts of technologies

According to Kumar (2000), three different waste-to-energy facilities such as incineration, sanitary landfill and gasification/pyrolysis have been compared on the basis of material input and output to identify the environmental impacts associated with them. It has been concluded that sanitary landfill has significant lower environmental impacts followed by gasification/pyrolysis and then incineration facility. However, all of these waste-to-energy technologies are not harmful to abiotic system and ozone layer because of energy recovered from waste. Based on environmental burdens (i.e. greenhouse gaseous emission and end residue), waste-to-energy technologies are ranked from least to most environmental impacts. This ranking is also considering the social impacts of technologies and it has been found that people are very strongly against the implementation of incineration plants due to its higher environmental impacts (Gruner, 2007), and followed by almost the same opposition for both anaerobic digestion and landfills.

1. Anaerobic digestion
2. Landfill gas production and utilization
3. Refused derived fuel
4. Gasification/pyrolysis
5. Starved air and mass burn incineration
6. Fluidized bed combustion
7. Rotary kiln

Anaerobic digestion is more favorable technology because it is helpful in high reduction of greenhouse gases and the digested organic matter left over from process used as a soil conditioner. Landfills are placed at second because the digested matter from the process remains in the system and is not used as manure. The produced leachate may have negative impacts on soil and on surface and groundwater and it can be eliminated through high engineered landfill designs. Refused derived fuel system is an efficient with high reduction of greenhouse gases and also with replacement of fossil fuel utilization in power plants etc. Gasification/pyrolysis have advantages over other technologies as this relatively produce clean emissions by reducing some toxic gases like dioxins, VOCs and NOx, that cannot be eliminated through other incineration facilities. Starved air incineration and mass burn incineration produces good quality of ash and air emissions compared to fluidized bed combustion process. Rotary kiln produces ash with high quantity of carbon content which is not assumed good and if produced in high amount, the quality of air emission becomes poor compared to above incineration technologies.

Anaerobic digestion process is more socially acceptable compared to landfills and incineration systems because of high reduction of greenhouse gases (a source of climatic change and groundwater contamination). Landfill/bioreactor landfills are relatively more appreciated by communities because these facilities are highly engineered and less costly compared to thermal treatment facilities and also produce less emissions. The source separation of generated solid waste produces less quantity of waste for disposal in landfills, this practice provides more free space for waste disposal over long period of time and ultimately less land will be required in future.

5.6 Cost and feasibility criteria of technologies

Economics of each type of waste-to-energy facility depends on specific composition and quantity of generated waste. According to conducted interviews with the top management of relevant district solid waste management department, do not have idea which type of energy recovery technology is most feasible and also having enough capacity to deal with current generated solid waste. Below it is try to discuss and find-out the capacities of various waste-to-energy technologies and find-out the best facility with enough capacity to deal huge quantity of generated waste from large towns of Lahore city.

5.6.1 Anaerobic digestion

Anaerobic digestion is relatively acceptable waste-to-energy option in Europe because there is limited land space for landfills establishment and the environmental friendly incineration technology is very costly (FCM, 2004). However, in case of Lahore the problem is to treat high quantity of generated organic waste in available capacities of anaerobic digestion plants worldwide.

Type of solid waste required

This type of waste-to-energy facility requires biodegradable material which is broken down through microbes in the absence of oxygen. The organic fraction may contain yard waste, paper waste, food waste and any other type of organic matter. The rest of organic fraction of waste stream such as bones, wood, rags, rubber and plastic etc. cannot be used in anaerobic digestion because of difficult natural degradation.

Available composition of solid waste for technology

The conducted study estimated the composition of Lahore solid waste. It is determined that 72% of organic fraction is present in waste stream. However approximately 56% organic waste such as animal waste, leaves, grasses and straw waste, paper and food waste can be utilized in anaerobic digestion facility and the rest (approximately 16%) of organic fraction like bones, wood, rags, plastic and rubber etc. is not favorable to use in this facility because these fractions of organic waste resist to degrade easily.

Available quantity of solid waste for technology

Anaerobic digestion technology for the processing of waste is mostly available in Europe. The commercial scale anaerobic digestion projects are working in Switzerland, Denmark, Germany, and France. The high capacity anaerobic digestion plants for the treatment of mixed waste are being constructed in Italy and Spain (FCM, 2004). Commercial level anaerobic digestion technologies from different 15 European countries are working on bio-waste, manure and mixed waste. These types of technologies are varying in capacity from 4000 to 220,000 tons/year. Among these, only few numbers of technologies are completely treating MSW and the numbers of these facilities are slowly increasing with the passage of time to treat only MSW (Kumar, 2000). The anaerobic digestion plants having the capacity to treat organic waste about 30,000 tons/year were construed in Europe between 1990-1995 years, but those plants which were constructed between 2001-2002 years having very high capacity i.e. 300,000 tons/year. One of the anaerobic digestion plant is operating in Town of Newmarket, Canada, have capacity to treat source separated organic plus mixed waste up-to 150,000 tons/year. This type of waste-to-energy facility is successful for the quantity of waste of 10,000 to 20,000 tons/year and the large facilities are under construction. Mostly European anaerobic digestion plants have 8,000-15,000 tons/year capacity to treat organic waste, but the recently constructed facilities have much more capacities about 40,000 tons/year (FCM, 2004).

The generated total quantity of organic waste in study area is approximately 4084 tons/day, from which approximately 3020 tons/day of organic waste fractions could be used for anaerobic digestion and the rest of organic waste fractions i.e. 910 tons/day are not easily degradable. The available high quantity of organic waste for processing is not feasible to treat in large anaerobic digestion facilities and also there is risk of loss of high amount of money to spend on such large projects because their outcomes are not yet predicted. However, it has been attempted to find out the cost per ton of some anaerobic digestion plants. It is clear that decrease in cost per ton with increase in quantity of waste for processing (Table 5.6).

Evaluation

The anaerobic digestion facility is not suitable for the produced organic waste from Lahore due to following reasons.

1) As we see that any facility has not enough capacity to treat generated waste in a combined anaerobic digestion plant from Lahore. It is concluded from review of anaerobic digestion facilities capacity that the maximum capacity to handle organic waste is about 300,000 ton/year, but the generated organic fractions from different 9 towns of Lahore was about 3020 tons per day.

2) If separately install three anaerobic digestion plants having capacity about 300,000 tons/year on three currently operating open dumping waste sites i.e. Mehmood Booti, Saggian and Bagrian disposal sites as described in Chapter 1.1 (Appendix 1), will not be capable to handle about 1000 tons/day generated organic waste.

3) The segregation of contaminants from organic fraction to avoid any impairment of system process adds more cost in the system.

Table 5.6: Anaerobic digestion facilities cost.

Waste quantity (ton/day)	**Cost** ($/ton)	**Location**	**Source**
30	180	Canada	FCM, 2004
140	100	Canada	FCM, 2004
270	80	Canada	FCM, 2004
500	a. 80 b. 65	USA	ARI, 2006
586	a. 56 b. 43	USA	ARI, 2006

(a). Private ownership and financing (base case), (b). Public ownership and financing (sensitivity)

5.6.2 Landfill gas production and utilization

Landfill gas recovery not only meets the energy requirements by displacing the conventional energy resources which are getting scarce and also has positive impacts on environment. Now days, landfill gas utilization for power production is considered as a commercial technology for energy generation. Several landfill gas waste-to-energy projects have been implemented and most of them are in America and Europe (Karapidakis et al., 2010).

Type of solid waste required

Solid waste composition has crucial rule in valuation of landfill gas recovery technology especially the moisture content, organic fraction and degradability level of different waste stream components. Large quantity of food fraction in landfill is easily degraded and tends to generate landfill gas within short period of time (SCS ENGINEERS, 2005).

Available composition of solid waste for technology

Almost the same composition of solid waste is required as in case of anaerobic digestion facility. There is approximately 56-60% organic waste fraction available for landfill treatment to generate and utilized gas for different energy purposes. The inert fraction like, glass, metals, plastic and rubber components etc. are not suitable for landfill gas recovery and may cause hindrance in the process. However, the organic fraction is in enough quantity in Lahore solid waste stream and is suitable for landfill gas production and utilization.

Available quantity of solid waste for technology

It is difficult to find out exact figures about the number of plants implemented worldwide because only few countries have centralized data about landfill gas projects. Landfill gas plants were initially practiced in US and afterward in Europe and today more number of plants are present in Europe than US. However, their capacity is half than the US landfill gas recovery projects. Now total 1,150 landfill gas recoveries for power production are operating worldwide and their capacity is varying from 2 million tons to 2,850 million tons of amount of waste (Willumsen, 2009).

The generated total quantity of organic waste in study area is approximately 4084 tons/day, from which approximately 3020 tons/day of organic waste fractions could be used for landfill gas recovery and the rest of organic waste fractions i.e. 910 tons/day are not easily degradable. The available high quantity of organic waste for processing is feasible to treat in landfill gas facilities and it is also supportive to replace scarce conventional fuels and generate revenue. It is attempted to find out the cost per ton of some landfill gas plants. It is clear to see that cost is decreased per ton with the increase in total quantity of waste for processing and negative sign indicates the generation of revenue (Table 5.7).

Evaluation

The landfill gas facility is suitable for the recovery and utilization of gas from high quantity of generated organic waste from Lahore solid waste stream. This facility requires relatively small capital cost compared to other waste-to-energy recovery technologies. Landfill gas facilities located near communities could be used as a source of CH_4 gas recovery and use it for energy purposes in houses and industries at lower cost to conventional power plants sources.

Table 5.7: Landfill gas facilities cost.

Waste quantity (ton/day)	**Cost** ($/ton)	**Location**	**Source**
274	-1	Canada	Tatarniuk, 2007
360	-3.55	Canada	Tatarniuk, 2007
550	4.6	Canada	Tatarniuk, 2007
1230	-0.25	Canada	Tatarniuk, 2007
192	6.73	Denmark	Johannessen, 1999
274	4.04	Poland	Johannessen, 1999
562	7.32	Indonesia	Johannessen, 1999
1918	3.89	Latvia	Johannessen, 1999
2740	3.85 (for enhanced bioreactor)	N/A	Johannessen, 1999
	2.91 (for not enhanced bioreactor)	N/A	Johannessen, 1999

5.6.3 Thermal treatment

Different types of technologies are grouped under thermal treatment that reduces the volume of coming waste stream and also results in the production of energy. Inert components of waste are avoided to use in this types of technology. Generally, thermal treatment technologies are divided into two groups: conventional and advanced thermal treatment. Fluidized bed combustion and mass burn technologies are considered under conventional treatment. The gasification, pyrolysis and plasma gasification are included in advanced thermal treatment, which are complex in process and are relatively not well known at commercial scale whereas the mass burn technology is commonly used worldwide (STANTEC, 2010).

The numbers of conventional facilities are under operation and approximately more than 400 are in Asia, 450 are in Europe, 87 are in U.S and 7are in Canada. It is estimated by the European Confederation of Waste to Energy Plants (CEWEP) for Europe that there will be 470 conventional plants in operation by the end of 2011 and 550 conventional facilities will be in operation by the end of 2016 (STANTEC, 2010).

Type of solid waste required

In thermal waste-to-energy technology, only the organic fractions such as plastic, combustible and putrescible are burnt in the system and as a result of which gases and residues are produced (Tatamiuk, 2007). The inert fractions of waste stream are avoided to make sure complete combustion of waste in the system.

Available composition of solid waste for technology

Approximately 72% fraction of the total generated waste stream is available for thermal waste-to-energy treatment technology. According to this type of waste-to-energy requirements, inert components (27.65%) and some other fractions of waste like metal and glass (1%) are not useable.

Available quantity of solid waste for technology

The available waste in Lahore is in enough quantity for the thermal treatment to generate enough energy and revenue. Approximately average 4045 tons/day generated waste in 2010 year from different 9 town of Lahore is suitable to treat in thermal waste-to-energy facility and the rest of waste such as inert, metal and glass (approximately 1626 ton/day), could not be used to treat in this type of facility.

Rotary kiln

Rotary kiln facility has been used for the treatment of MSW since 1950 and is also used for the other type of solids and hazardous liquid wastes. The typical capacities of rotary kiln are in range from 10 to 50 tons/day (FCM, 2004). Those rotary kiln incinerators which are operating other than US since 1960 are in capacities range from 152 to 1090 tons/day and average in capacity is approximately 480 tons/day (Tatarniuk, 2007).

Mass burn technology

More than 90% (total 420 mass burn out of 450 W-T.E plants) operating waste-to-energy technologies are mass burn in Europe and with maximum capacity of this facility to treat waste are about 750,000 tons/year. Mass burn facilities are generally ranged in capacity approximately from 36,500 to 365,000 tons/year. These waste-to-energy facilities consist of multi furnaces and can be expanded with the addition of other units. Calorific value of treated waste defines the capacity of mass burn incinerator. Generally the mass burn facility having the maximum capacity is about 280,000 tons/year in Europe by considering the waste has calorific value about 11 MJ/kg. Nowadays there is a trend to built relatively large size facilities in Europe (STANTEC, 2010). Mass burn facilities are in capacities range from 100 to 1,000 tons per/day per unit and a facility with 5,000 tons/day are operating in North America. However, those facilities which are operating in Canada are generally range in capacities from 400 to 850 tons/day (FCM, 2004). One large mass burn facility with capacity about 140,000 tons/year is being proposed for implementation in Canada and can be expanded to process waste 400,000 tons/year. Produced fine ash from the system is a major source of air pollution (STANTEC, 2010).

The other two conventional waste-to-energy facilities such as fluidized bed combustion and modular, two-stage combustion are relatively less used for the management of MSW. Often modular, two-stage combustion is considered as a type of gasification but is not a true gasifire and simply referred as a conventional waste-to-energy technology (STANTEC, 2010).

Starved air incineration

The typical capacities of semi-continuous starved air incinerators range from 10 to 100 tons/day and typical capacities for batch process starved air incinerators range from 0.5 to 3 tons/day. These types of facilities are suitable for small municipalities (FCM, 2004).

Fluidized bed combustion

Fluidized bed combustion is a type of waste-to-energy treatment varies in capacities range from 50 to 500 tons/day (FCM). Homogeneous solid waste is used in fluidized bed combustion. Currently approximately 30 mass burn facilities are operating in Europe and also two large facilities are implemented in Canada. The numbers of facilities are either under planning or development stages (STANTEC, 2010).

Gasification and pyrolysis

At the end of 2009 there were 9 gasification facilities operating in Japan to process MSW. Other than Japan, only limited numbers of gasification facilities are in operation due to complex operational system technology that requires only homogeneous waste stream. Gasification facilities have high capital and operational cost compared to conventional waste-to-energy facilities. Currently no commercial gasification plant is operating in Europe for the treatment of municipal waste because it is expensive and unproven technology. One commercial gasification facility was treating municipal waste in Germany and it was closed in 2004 due to financial and technical factors. There are approximately 7 gasification plants operating in Japan within past 10 years due to environmental regulations which are different from other countries in context of net dioxin emissions from all sources such as ash, waste water and air (STANTEC, 2010).

Solid waste with 60% organic matter is suitable for pyrolysis waste-to-energy facility. One commercial scale pyrolysis facility having capacity about 100,000 tons/year was operating in Germany during 1997 but it was closed on August, 1998 due to technical problems. Recently no such facility is operating in Europe. However, one small scale facility has been operating in Burgau. There were six such type facilities closed at the end of 2007 in Japan. A new facility with capacity of treatment of waste about 450 tons/day was built during 2007-2008 in Hamamatsu (STANTEC, 2010).

Evaluation

There is only one thermal waste-to-energy facility (i.e. mass burn incineration) which seems to have ability to handle or treat generated MSW in Lahore. The summary of waste treatment cost/ton of different thermal technologies is described in Table 5.8, which includes capital and operational cost.

Rotary kiln incinerator

Rotary kiln incinerators are not commercially well known for the treatment of waste. The available capacities of such incineration plants are not enough to treat generated waste in Lahore. The capacities are generally in range from 10 to 1090 tons/day; with an average of about 480 tons/day. However, recently available quantity of solid waste is about 4045 tons/day and such of these three waste-to-energy plants will be required on three different landfill sites in Lahore with maximum capacity (i.e. 1090 tons/day), but still some waste will be left over without treatment. The combined annualized capital and operational cost are determined over the period of 25 years, which is in range from 125 to 150 $/ton of waste processed. This facility is a source of air pollution and installation of pollution control system adds extra cost in facility.

Mass burn technology

This type of waste-to-energy facility is acceptable for large towns in Lahore. The maximum capacity of mass burn facility is approximately 750,000 tons/year (2054 tons/day) and generally this facility capacities range from 36.500 to 365,000 tons/year (100 to 1000 tons/day). It is most famous waste treatment facility throughout Europe and also now days, there is a trend to construct large size facilities in Europe. There will be such two facilities required with maximum capacities to treat current available waste stream in city.

Starved air incineration

The starved air incineration plants are ranged in capacities from 0.5 to 100 tons/day to treat waste, which are only suitable for small municipalities. The treatment cost varies from 100 to 200 $/ton of waste treatment.

Fluidized bed combustion

Fluidized bed combustion generally vary in capacities range from 50 to 500 tons/day and associated cost is about 110 to 80 $/ton respectively of waste treatment. One large such facility with capacity of 140,000 tons/year (384 tons/day) is operating in Canada and can be expanded to 400,000 tons/year (1096 tons/day). However, it is difficult for such capacities of fluidized bed combustions plants to treat a huge quantity of available waste stream from different towns of Lahore.

Gasification and pyrolysis

Gasification and pyrolysis technologies have high capital and operational cost compared to conventional waste-to-energy facilities. There are only limited such facilities in operation worldwide. No plant is operating at commercial scale in Europe (waste-to-energy report). However, both are emerging technologies and are yet to be commercially implemented for the management of MSW in Europe (FCM, 2004). Only few such plants are operating in Japan. One plant operating in Germany has capacity to treat solid waste approximately 100,000 tons/year (274 tons/day). A new facility with capacity of treatment of solid waste about 450 tons/day (164250 tons/year) was built during 2007-2008 time period in Hamamatsu.

It is difficult for such type of facilities to handle very high quantity of generated waste per day in Lahore. Even such these three plants construct on three operating open dumping sites; still it will not be able to cope with situation in city.

It was also tried to find out proposed facility capacities to handle New York generated MSW and cost data about established such type of projects from different countries was gathered and calculated cost for commercial scale projects for 2014 year is shown in Table 5.8. The capacities of such W-E-T plants range from 2612 to 2959 tons/day. Such type of capacities of gasification/pyrolysis facilities can handle generated MSW in Lahore but in actual situation results could be haphazard because these are emerging technologies.

Table 5.8: Thermal treatment facilities cost.

Types of thermal treatment technology	Waste quantity (ton/day)	Cost ($/ton)	Location	Source
Kiln incinerator	10	150	Canada	FCM, 2004
	50	125	Canada	FCM, 2004
	90	100	Canada	FCM, 2004
Mass burning	400	85	Canada	FCM, 2004
	850	65	Canada	FCM, 2004
	1500	65	N/A	R.W.BECK, 2010
Starved air incinerator	0.5	200	Canada	FCM, 2004
	3	72	Canada	FCM, 2004
	10	150	Canada	FCM, 2004
	100	100	Canada	FCM, 2004
Fluidized bed incinerator	50	110	Canada	FCM, 2004
	500	80	Canada	FCM, 2004
Refused derived fuel	500	25	Canada	FCM, 2004
	500	100	Canada	FCM, 2004
Gasification/pyrolysis	600	100	Canada	FCM, 2004
	71	408	Canada	FCM, 2004
	71	360	Canada	FCM, 2004
	71	806	Canada	FCM, 2004
	71	57	Canada	FCM, 2004
	2612	a. 103 b. 76	USA	ARI, 2006
	2729	a. 165 b. 129	USA	ARI, 2006
	2758	a. 134 b. 104	USA	ARI, 2006
	2959	a. 141 b. 96	USA	ARI, 2006

a. Private ownership and financing (base case)

b. Public ownership and financing (sensitivity)

5.7 Comparison of technologies cost

The information required for the comparison of cost associated with waste-to-energy recovery technologies has been studied and presented in systematic manner such as; type of waste composition, suitable quantity of waste required and cost associated with different technologies according to their capacities throughout worldwide.

These different types of energy recovery options are affected by quantity and composition of generated waste stream. All of these technologies do not utilize inert components of waste.

The following three main waste-to-energy recovery technologies are considered.

- Anaerobic digestion
- Landfill gas production and utilization
- Thermal treatment technologies

It has been seen that the cost/ton of waste treatment decreased with the total increase in quantity of waste available for treatment in all waste-to-energy facilities. By subtracting the cost from revenues gives the potential profits of different technologies, which is the main aim of conducted study to come up with best waste-to-energy option. The solid waste treatment cost of different treatment technologies are compared only on the basis of final cost/ton (summarized in Table 5.6, 5.7 and 5.8). Generally, this cost could be split into capital, operating and maintenance cost.

From comparison of cost of various waste treating options it has been concluded that landfill facility has the minimum cost per ton compared to other options. However, landfills cost varies between -3.5 $/ton to 4.6 $/ton. The bioreactor landfill could be the more suitable option as compared to ordinary sanitary landfill because in bioreactor landfill leachate circulates to enhance degradation of organic fractions of waste. This not only reduces the land space for disposal of waste but also produces more gas in short period of time to generate more revenue. The waste-to-energy technologies could be ranked on the basis of cost/ton as:

1. Landfill gas production and utilization
2. Thermal treatment
3. Anaerobic digestion

The anaerobic digestion is considered as third option because the capacities of waste treatment plants are not enough to handle generated MSW in Lahore. However, few options within thermal treatment facilities have enough capacities to treat current produced waste in Lahore at comparable cost with anaerobic digestion.

5.8 Most feasible form(s) of technology(ies)

Different types of waste-to-energy recovery technologies were studied by considering the main factors such as social, environmental and economic which play an important role while the section of best energy recovery technology(ies) for large towns of a big city Lahore. The cost associated with each type of energy recovery technology is directly linked with the available quantity of waste stream for processing as well as its composition. From social and environmental issues, environmental impacts of technologies are more important and must be considered separately. The mitigation of impacts adds extra costs in technologies. These such issues are already discussed in chapter 5.

Following are the most feasible form(s) of technology/ies selected for large towns of Lahore:

1. Landfill/bioreactor landfill gas production and utilization
2. Mass burn incineration

Landfill gas recovery technology (sanitary landfill/bioreactor landfill) is the most socially acceptable, environmentally friendly and the cheapest one among all other available worldwide waste-to-energy technologies for large towns of Lahore.

Mass burn incineration is the second best option because it is relatively socially unacceptable, more source of pollution and likewise more costly than the landfill gas recovery facility.

From both fluidized bed combustion and gasification/pyrolysis waste-to-energy technologies one could be the third best option for waste management of big towns of Lahore, but in both cases major different types of drawbacks are present. Even fluidized bed combustion is relatively cheap but it is a source of pollution. Moreover, the plants with this thermal technology have not enough capacity to treat whole waste per day. The major drawback of gasification or pyrolysis technologies is that these are the emerging technologies and their outcomes/results could be haphazard.

The other remaining waste-to-energy recovery options such as anaerobic digestion, rotary kiln incineration, starved air incineration and refused derived fuel are excluded because of their technical viability, social, environmental and economic factors as discussed in chapter 5.

6 Conclusions and recommendations

6.1 Conclusions

The selection of feasible technology for a large city Lahore, social, environmental, economic, and composition & quantity of waste factors were considered during evaluation process of different waste-to-energy available options. The economic parameter remained the most influential than the other factors during the selection process of technology, because of country economic conditions and limited allocation of budget towards the waste management sector. The current composition of waste was determined and consists of approximately 28% inert, 53% wet organics, 1% glass and metals, 13% dry combustibles and 6% rubber and plastics. Following conclusions could be drawn from the feasibility study of waste-to-energy technology selection in this study.

The composition of solid waste from Lahore remained almost the same from 2004 till 2010 (Figure 5.1). With the increase of population growth, 147573 tons of waste has been added in total quantity of waste from 2007 to 2010 (Table 5.1). Therefore, Lahore Waste Management Company has no good data to show the effects of different levels of economic condition of communities and population growth on waste generation of Lahore city. Lahore Waste Management Company using the different common factors each year i.e. 0.65 ton/person/day in 2007 and 0.7 ton/person/day in 2010 (Tables 5.2 and 5.3), which were determined from single waste disposal site i.e., Mahmood Booti, and generalized it over all towns of Lahore to estimate the overall waste generation per day by multiplying with each year's population growth.

Landfill gas production and utilization and mass burn incineration are standalone most feasible technologies at first and second potion respectively for treatment of solid waste in Lahore. It is because; these two facilities have enough capacities (i.e., maximum worldwide operating capacities in range from 2 million tons to 2,850 million tons per year for landfills and 750,000 tons/year for mass burn incineration) to treat the current generated waste at lower costs per ton (i.e., cost varies is in range from -3.55 $/ton to 6.73 $/ton, if waste quantity is in range from 2740 to 192 tons/day for landfill and 65 $/ton to 85 $/ton, if quantity waste is in range from 1500 to 400 tons/day for mass burn incineration), (section 5.6), with minimal social and environmental impacts as compared to other waste-to-energy facilities (section 5.4). These two facilities, also having capabilities to expand their capacities, if needed to treat more waste in future. However, the treatment cost per ton decreases with the increase in quantity of waste per day.

6.2 Recommendations

The study about the feasibility of waste-to-energy recovery technologies have never been carried out in any province of Pakistan. In this study, it has been tried to estimate the current composition and quantity of produced waste in Lahore and also to explore the social, environmental and economic issues closely related to improper solid waste management and in-depth study of technologies which are especially designed for the handling of waste. Local municipalities should consider waste-to-energy recovery technologies for the handling of their generated solid waste to save the more extraction of natural resources, to generate revenue and improve local socio-environmental conditions of an area. However, to implement waste-to-energy facility in Lahore, following things must be considered.

- Lahore city should be divided into different sectors such as commercial, residential and industrial sectors etc. in order to determine the exact composition and quantity of generated waste from sector for effective solid waste management.
- Solid waste composition and quantity should be determined throughout years for all seasons and also separately for different income groups etc.
- Educate people about improper solid waste issues and also give awareness about benefits of waste-to-energy technologies for effective cooperation between municipalities and communities.
- In future, further research should consider more new and emerging waste treatment technologies.
- The decision about the final implementation of waste-to-energy technology, politician should make their decisions strictly in-line with experts/professionals findings.

6.3 Shortcoming of study

Quantity of generated waste per day was found by Lahore Waste Management Company only at single waste disposal site i.e. Mahmood Booti, available among three waste disposal sites and generalized it over rest of Lahore’s towns to estimate the overall waste generation in city, without splitting it into different economic towns. Therefore, without determining the exact quantity of solid waste generation per capita in Lahore may produce uncertainties in investment of costs and also on technical parameters of selected waste-to-energy technology that may lead to country's economic losses and improper waste management strategy of the city.

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Appendix 1: Maps of open solid waste dumping sites in Lahore, Pakistan.

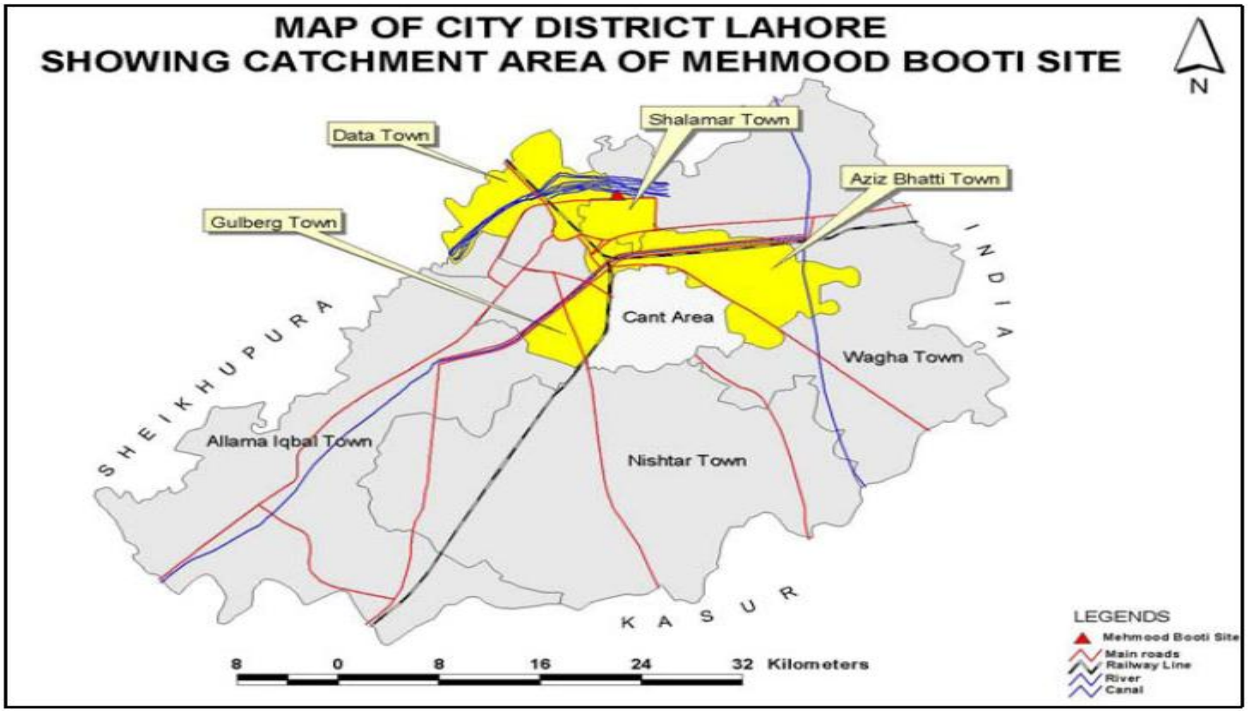

Figure 1: Local map for Mahmood Booti solid waste dumping site (Imtiaz, A., Ali, H. 2008).

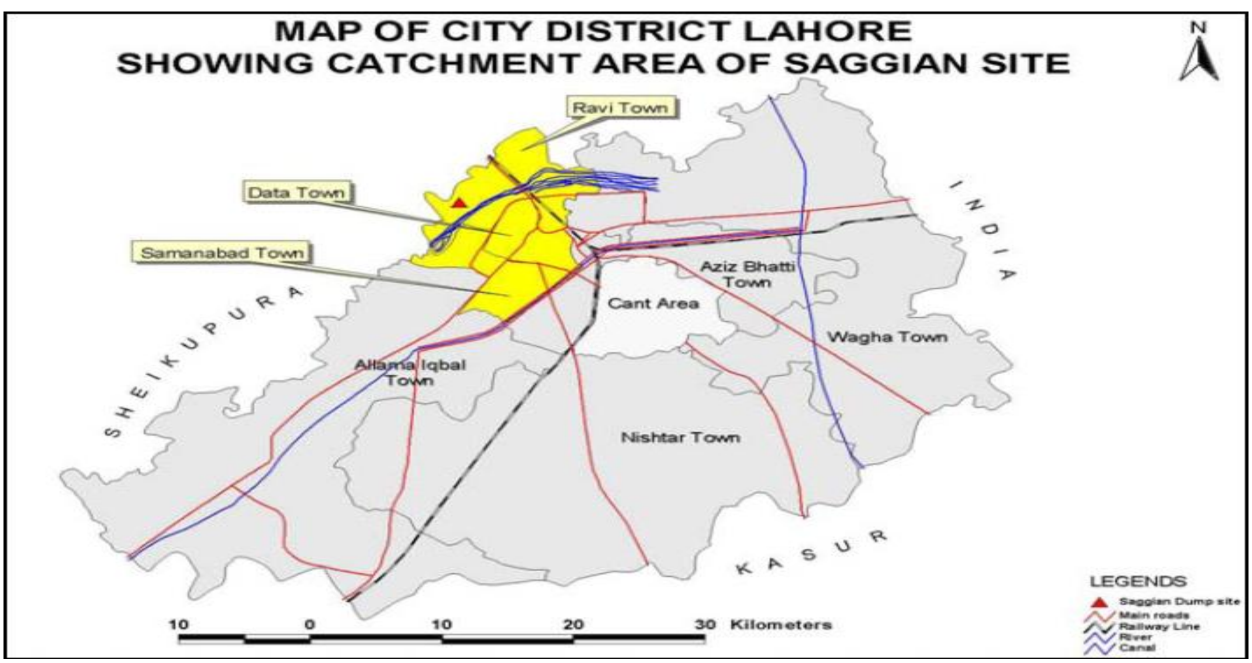

Figure 2: Local map for Saggian solid waste dumping site (Imtiaz, A., Ali, H. 2008).

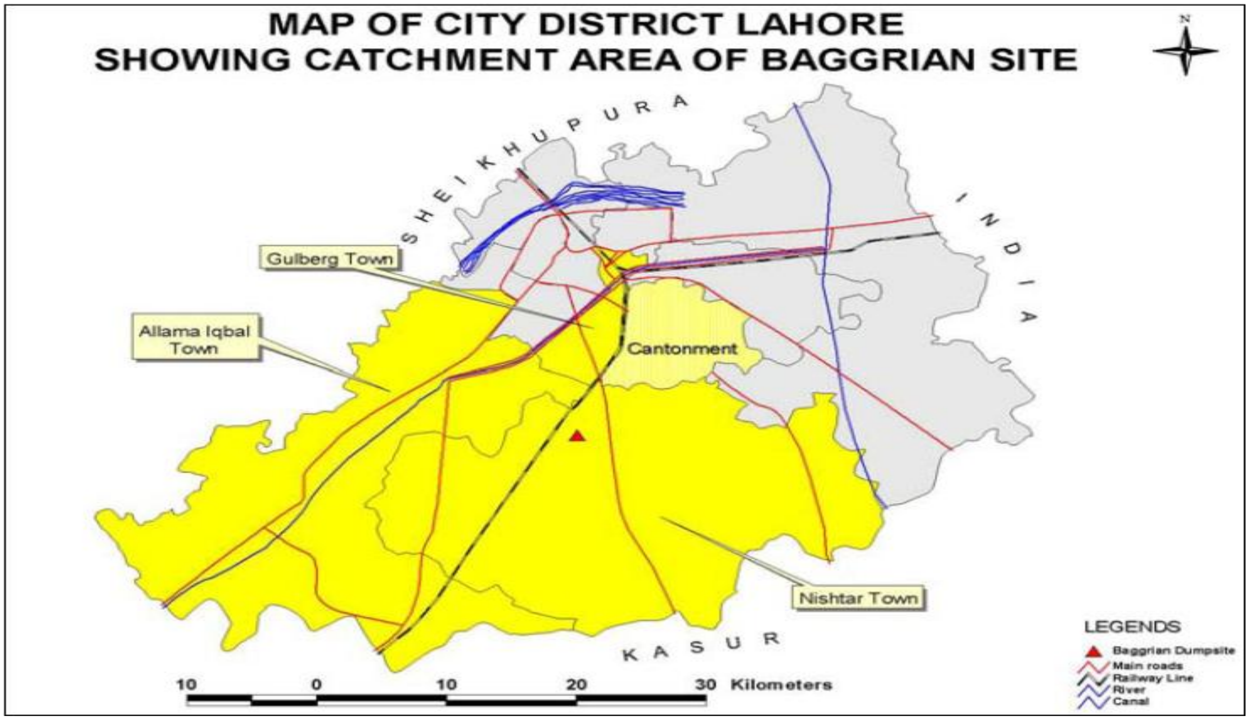

Figure 3: Local map for Baggrian solid waste dumping site (Imtiaz, A., Ali, H. 2008).

Appendix 2: Pictures

Pictures of solid waste management process in Lahore, Pakistan.

Solid waste collected in street.

Scavengers collecting useful material from collected waste in street.

Scavengers collecting useful material from open dumping site.

Manual loading of solid waste.

Solid waste collection tractor.

Solid waste collection truck.

Transportation of waste to Mahmood Booti dumping site.

Unloading of waste on Mahmood Booti dumping site.

Collection of leachate on open dumping site.