Energy Generation from Municipal Solid Waste of Kabul City; Creating Opportunity from Setback

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Abstract - Kabul city, the capital of Afghanistan, has experienced wide-ranging changes in spatial and socio-economic patterns during the last few years, supported by international co-operation, especially the United States and other developed and developing countries of the world. The changes have produced extensive increase in generation of municipal solid waste (MSW) and demand for electricity. Open landfilling is unfortunately the dominant method of MSW disposal in the city. This research aims to assess the value of Waste-to-Energy (WTE) facility as a solution to MSW landfill problem and to both get rid of accumulation of MSW and address energy shortage issue. Few Waste-To-Energy scenarios are developed lately: complete incineration; incineration with recycling, Refused Derived Fuel (RDF), Biomethanation, gasification and pyrolysis. The research show that Kabul has the potential to produce about 80.2 MW of electricity based on MSW. These values are based on data from respective organizations and methodology for calculating the potential energy production of the MSW. This study mainly focuses on capacity of MSW of Kabul city for energy production and its potential to be used as a considerable source of energy and electricity.

Key words: Municipal Solid Waste (MSW), Waste-To-Energy (WTE), incineration, gasification, pyrolysis.

1. INTRODUCTION

Kabul City has experienced enormous changes in spatial and socio-economic patterns during the last few years. Due to fast population increase and high economic growth rate based on international aid and co-operation, there has been a rapid growth in urbanization. Population growth, urbanization, rise in living standards and many other factors have all dramatically accelerated the MSW generation in city. The CSO of Afghanistan has announced total population of the country 32.2 million as of 2019. From which about 16.4 million (51%) are male and 15.8 million (49%) are female. Around 23 million (71.4%) of people live in rural areas, 7.7 million people (23.9%) live in urban areas and 1.5 million (4.7%) are nomadic population [1]. Considering high urbanization rate of Afghanistan, more than third of the country inhabitants will live in urban areas by 2025, which could consequently have an adverse effect on urban, social and economic development. Demographic distribution in Afghanistan is concentrated in Kabul, the northern and eastern provinces of the country, as they are commercial hubs and businesses tend to proliferate in urban areas. Kabul is the capital of Afghanistan and has a current population of around 5 million. The long term average population growth is about 2.4%. MSW management is a challenging chronic problem in Kabul city, as the infrastructure of the city was built for much lower number than its current inhabitants.

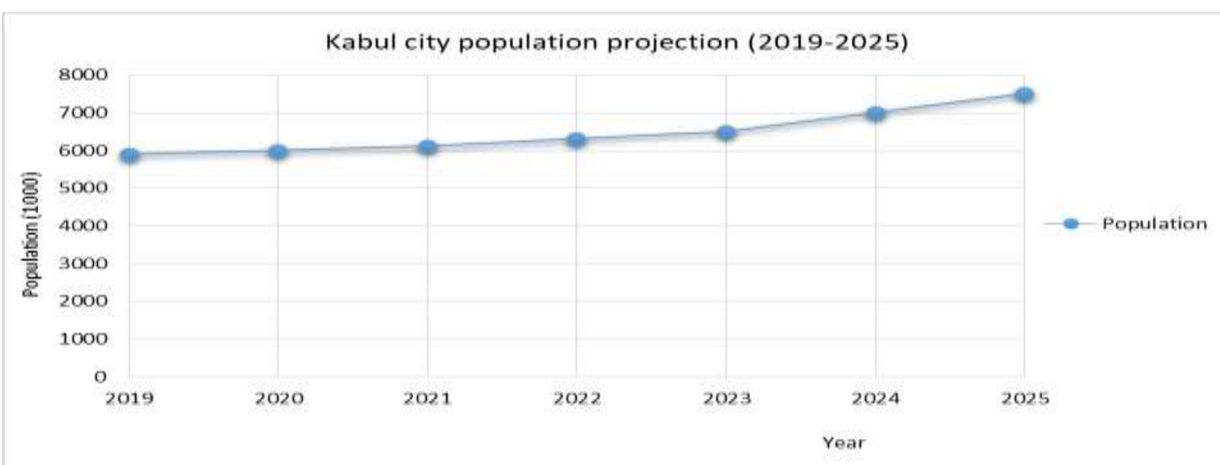

Fig 1. Projected population of Kabul city (2019 to 2025) [2].

The current municipal solid waste management system in Kabul city is simple, but with very dangerous consequences: collect and get rid of it by dumping it in open landfill sites. The substantial quantity generated by MSW in the city and the high energy content of its composition demonstrate the significant potential for establishment of WTE facilities in the city.

There are primarily five WTE technologies widely used and implemented for MSW management worldwide, namely: incineration with energy recovery, pyrolysis or gasification, plasma arc gasification, refused derived fuel (RDF) and Biomethanation. In this study, mainly incineration was focused. Incineration is the production of energy from waste through combustion, which has remained to be the most integral part of MSW management in many countries, due to its simplicity, easy implementation and lower economic costs. RDF is a clean and efficient method of producing an alternative fuel for power generating industries, which runs on coal fuel. Biomethanation converts the Organic Fraction of Municipal Solid Waste (MSW) into useful energy.

2. Generation of MSW in Kabul city

Kabul is the capital and most populous city of Afghanistan, which houses nearly fifth of the country's population. Being the national capital and a major commercial center caused it to be witnessed continuous stream of migrants from all parts of the country since establishment of the new political era in the country in 2001.Population growth and unplanned urbanization has increasingly contributed to the generation and accumulation of solid waste in Kabul city. Residents of the city are just disposing their waste at a nearest collecting point (CP) without separationist sorting or proper packaging at home. On weekdays, Department of Sanitation (DoS) of Kabul Municipality dispatches collection vehicles to CPs, and transport the accumulated wastes to the disposal sites in Chamtala region of the province for open dumping. The disposal is by open dumping, and no truck scale is provided at the site to measure the solid waste weight. The wastes are not covered with soil and also no lining sheet is laid to prevent the leachate from penetrating into underground [2]. Up to now about 6 million Tons of MSW are accumulated in Kabul city, which can be used as a source of energy in the future and also will solve the problem of its accumulation and its adverse ecological effects. If this problem will not be addressed soon, it can become environmental crises across the country.

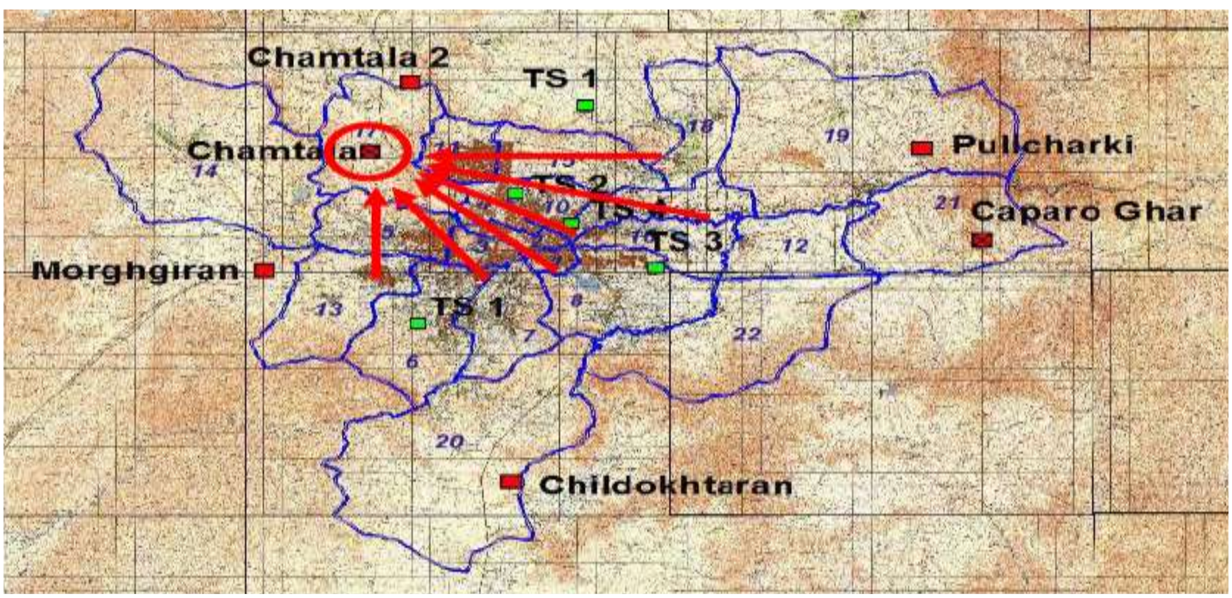

Fig 2. Present solid waste disposal site in Kabul city (source ibid) [36].

In Kabul city there are many public institutions generating solid wastes beside households, such as governmental and private sector offices, schools, public markets, hospitals, industries and etc. The characteristics of most of these institutional wastes are the same as the domestic waste, though the compositions may be somewhat different from different sources. For example, more paper is found in wastes from governmental offices, and more organic matter is found in market and household wastes. The institutional wastes are currently dealt together with the domestic wastes.

In 2003 UN-HABITAT conducted a survey on solid wastes in Kabul. According to the survey, the total amount of generated solid wastes is 451,000 T/year. The survey was based on population of the city 3.09 million by then and production of waste 150 kg/capita/year, or 0.4 kg /capita/day. This amount tends to increase simultaneously with improving living standards. Today Kabul city have about 5 million population, which according to the above mentioned statistics the waste product may be near 875000 T/year, which is practically far more than this value today, as the increase in standards of livings also caused increase in amount of waste produced per capita per day. The solid wastes in Kabul consist mainly of organic matter such as kitchen wastes, tin cans, plastic material and glassware. There are also some textiles to a negligible extent. According to the survey, organic matters in the solid wastes account for 57% in weight fraction, paper and plastics 15%, and others including metals and glass 28%. While the amount of solid waste generated and collected is projected to reach 3,300 Tons/day by 2025 (36).

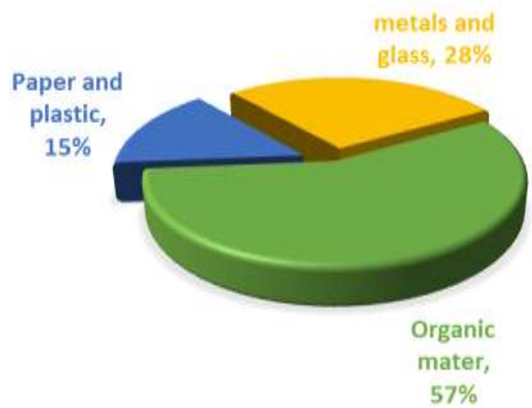

Fig 3. MSW composition of Kabul city [2].

The amount of waste generation per capita is also an indicator of living standards. The value of 0.4 kg/capita/day continued at the same level until 2016 and after that it show slight increase it will as the living standards improved. The figure in 2020 is estimated at 0.5 kg/capita/day and in 2025 at 0.6 kg/capita/day as shown in Figure 4 [36].

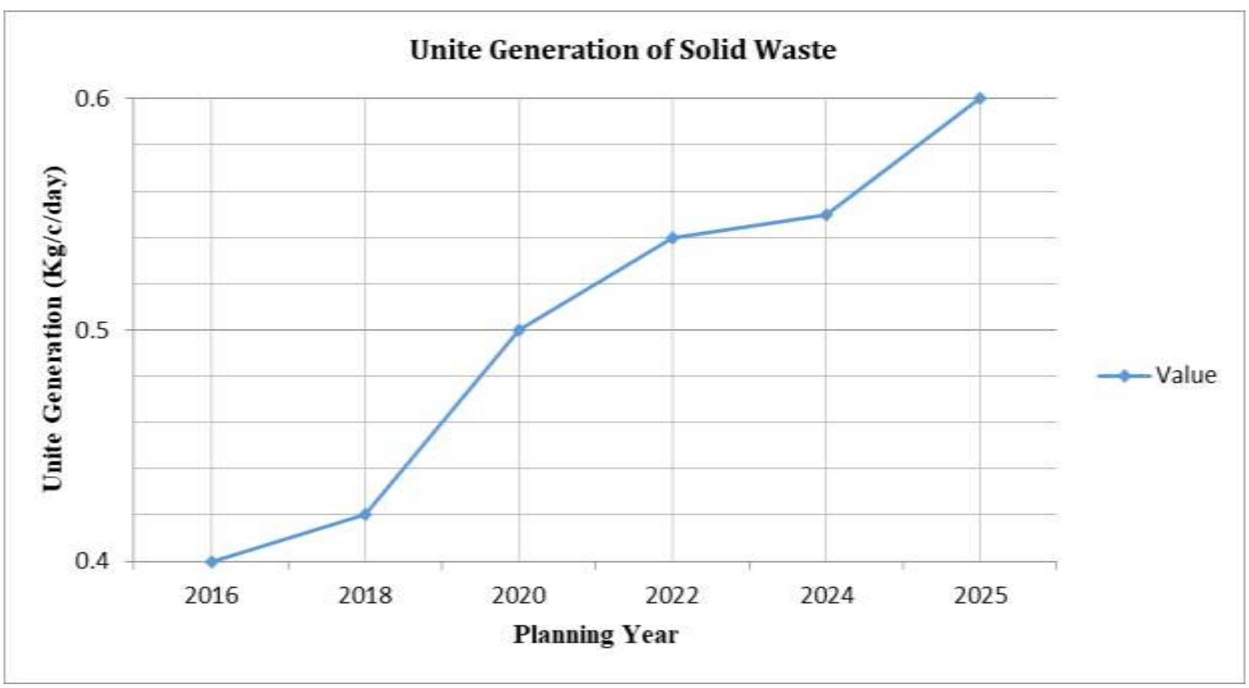

Fig 4. Trend of Unit Solid Waste Generation [36].

The collection ratio shall increase to 100 % by 2025, after gradual increase from 25% in 2008 to 50% in 2015, and 75% in 2020 (Table 1. and 2). In accordance with the population, the amount of solid waste generation has been estimated to increase as shown in Table 2. In the future, the gap between the generated and collected amount of the waste would minimize and would finally reach zero in the targeted year of 2025.

Tab 1. Projected population, unit generation and collection ratio in Kabul city from 2008 to 2025 [36].

Year	2008	2010	2015	2020	2025
Population ($X10^3$)	4,007	4,271	4,931	5,267	5,602
Unit generation (kg/c/day)	0.4	0.4	0.4	0.5	0.6
Collection ratio (%)	25	25	50	75	100

Tab 2. Total amount of solid waste for disposal in Kabul city from 2008 to 2025 [36].

Year	2008	2010	2015	2020	2025
Generation amount (1000 T/y)	1,603	1,709	1,973	2,634	3,362
Disposal amount (1000 T/y)	401	427	987	1,976	3,362
Increase ratio	100	106	246	493	838

Fig 5. Open dumping of MSW in Kabul city [5].

3. Waste to energy recovery

The energy from waste can be directly derived by converting waste into biogas, syngas or heat. The technological method for converting energy from waste can be divided into three types, which are physical, thermal and biological methods (fig 6).

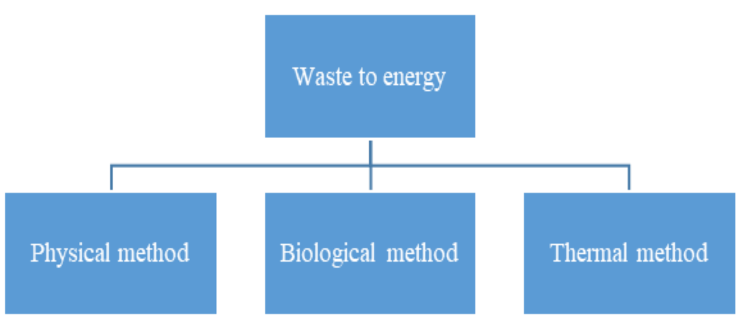

Fig.6. Schematic diagram of waste to energy management methods [27].

3.1 Physical method

In physical method waste is processed mechanically to produce more suitable, durable and hand-able form that is used as a fuel for further processing. Examples of mechanically derived form are pellets, wood chips, and wood briquettes (more recycling raises average energy content of waste used to generate electricity (U.S. Energy Information Administration, 2012). [27].

3.2 Biological method

Biological method or more precisely Mechanical Biological Treatment (MBT) is a type of facility for WTE which consist of both sorting facility and biological treatment of the waste such as composting, anaerobic digestion or bio-drying. In this method, not only municipal solid waste (MSW) is treated, but also commercial and industrial can be used as raw material for further processing and WTE.

3.3 Thermal methods

There are few thermal methods used for generation of energy from waste. The most common Thermochemical technologies for conversion of MSW are as below:

a) Incineration or full oxidation
b) Pyrolysis or partial oxidation
c) Gasification or thermal degradation of organic material in the absence of oxygen
d) Plasma arc incineration

4.3 Incineration

The main common purpose of incineration is to treat MSW, reduce its volume and hazardous characteristics and also to produce heat and electrical energy for further uses. Incineration is a useful process for treatment of very wide range of MSW from domestic waste to commercial and industrial waste. It is the oxidation of combustible material of MSW. Generated flue gases during incineration contain majority of the available fuel energy as heat [27].

Energy recovery value in incineration process can be calculated by below mentioned equation (7).

$$ERP_i = \eta \cdot M \cdot LCV_i / 1000$$

Where:

ERP_i- Energy recovery potential (MWh/day)
η- Process efficiency coefficient (%)
M- Total amount of MSW (t/day)
LCV_i- Low Caloric Value of the raw material (KWh/Kg)

As incineration is the combustion of MSW, it causes production of some environmentally dangerous compounds, which should not be present in atmospheric air or should be present in accordance to standards and criteria. For this reason, produced gases must be filtered before exiting to the atmosphere, in order to reduce dangerous components in its composition. Besides, furnace should designed and constructed wisely, in order to have higher efficiency.

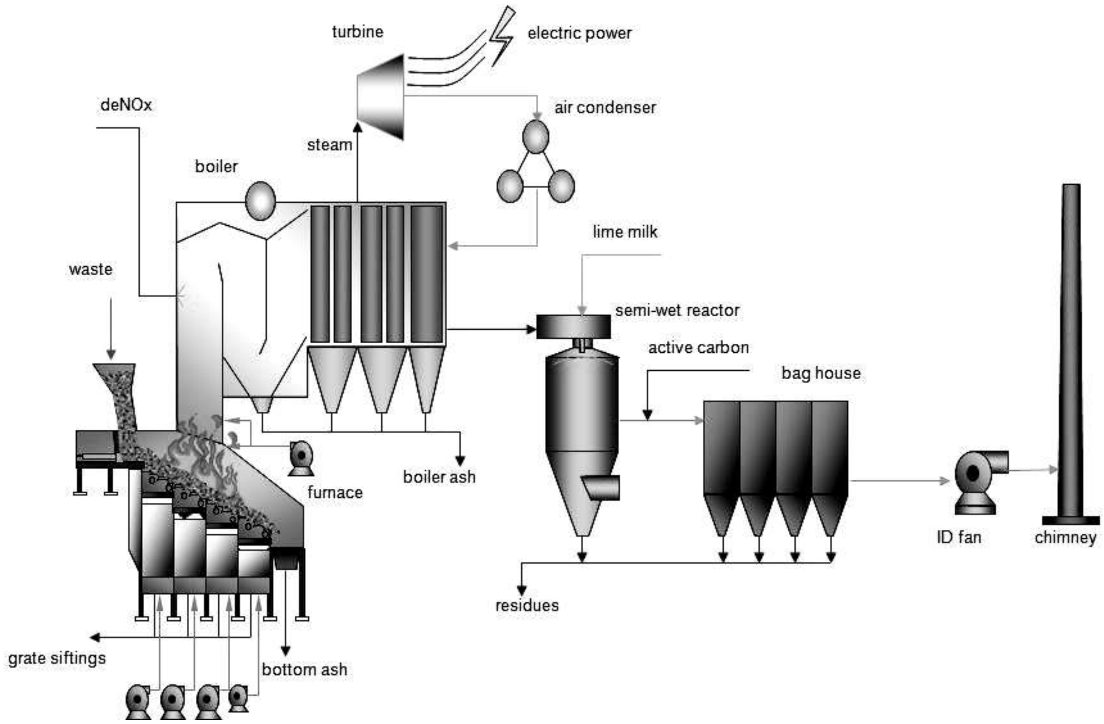

Fig 7. Incineration scheme [10].

The incineration process has many strengths and benefits, which are mentioned in the book "Waste management" where the most important points are:

Most important strengths and benefits of the incineration process are reduction of large volume of MSW, thermal destruction of pathogens, organic material and bad smell elimination, technology maturity, less area needed for material storage, simplicity of the process (lower process temperature), and most importantly its integration possibility in Kabul city [27].

Beside its many strengths and benefits, it can also have many weaknesses. For example low energy efficiency comparing to other two other thermal WTE methods, because of low steam quality due to low temperature of produced steam, need for initial drying of MSW, ash and heavy metals disposal problems, difficulties in cleaning and sorting of MSW before incineration, and most importantly hazardous effects of environmentally dangerous produced particles and gases and its sorption problems before releasing it to the atmosphere.

5.3 Gasification

Gasification is another method for handling municipal solid waste (MSW). Main difference of this method wish incineration is their final product, which is fuel in gasification and thermal energy in incineration. The fuel or more specifically syngas produced in this process can be further used for thermal or electrical energy production. Beside energetic point of view, produced fuel can be also a good raw material for producing valuable chemical products.

Gasification is the process of conversion of organic raw material into gaseous products in the presence of gasification agent at very high temperatures. The gasification agent facilitates the conversion of organic material into gaseous products and it acts as catalyst. As result of gasification beside main gasification products, such as hydrogen, methane, carbon dioxide and carbon monoxide; few other by-products are also produced such as gas pollutants, inert gases and gasification process waste.

Gasification as a thermochemical process consists of two different stages. The first stage is the pyrolysis which causes production of volatile components at temperatures below 650°C and in second stage produced volatile gases react with steam, air or pure oxygen in order to produce the final product of the gasification process which is syngas. However syngas is the main product of the gasification process, but its composition is primarily determined by compound used for reaction in second stage. If air is used for reaction with volatile compounds, then N_2 will be the dominant gas in produced syngas, but if steam or pure oxygen is used for reaction, the unlike air the final product may have higher Btu value and also the dominant gas, beside hydrogen would be carbon dioxide and carbon monoxide in steam and pure oxygen usage respectively [2].

Very low amount of steam or oxygen is used in gasification process in order to convert organic matter into combustible syngas. The most important advantage of this method than combustion is the final product of gasification which is syngas that can be further used for thermal or electrical energy production purposes. Another advantage of this method is its high efficiency of energy recovery and less emission than incineration. The disadvantage of this method is sophistication of the pre-processing of the MSW to RDF (Refuse Derived Fuel) and removal of formed inorganic compounds before using the fuel for combustion purposes. High investment and maintenance cost and complexity of the technology are other disadvantages of the technology [2].

6.3 Pyrolysis

Pyrolysis is a method of waste treatment in the absence of atmospheric air. This technology is low capital cost, less polluting and with easy transportable final product than incineration. Based on the parameters there are three types of pyrolysis, which are: slow, fast and thermolysis. Basis parameters of these three types of pyrolysis are mentioned in Tab 3 [1].

Tab 3. Sub classes in pyrolysis process [1].

Parameters	**Sub classes**		
	Slow	Fast	Thermolysis
Temperature (K)	550-900	850-1250	1050-1300
Heating rate (K/sec)	0.1-1.0	10-200	>1000
Particle size (mm)	5-50	<1	<0.2
Retention time (sec)	300-3600	0.5-10	<0.5

Temperature of more than 300°C and less than 800°C are maintained for the process of MSW pyrolysis. Syngas which is the product of this process is composed of two phases, one combustible gas and the other noncombustible char as solid residue. Produced syngas usually has good Net Caloric Value (NCV) of between 10 and 20 MJ/Nm^3. Comparison of pyrolysis, gasification and combustion are written in Tab 4.

Tab 4. Comparison of three WTE thermal methods [20].

Parameters	**Pyrolysis**	**Gasification**	**Combustion**
Temperature (°C)	250 – 900	500 -1800	800 – 1450
Pressure (bar)	1	1 – 45	1
Atmosphere	Inert/nitrogen	Gasification agent: O_2, H_2O	Air
Stoichiometric ratio	0	< 1	> 1
Products of the Process			
Gas phase	H_2, CO, H_2O, N_2, hydrocarbons	H_2, CO, CO_2, CH_4, H_2O, N_2	CO_2, H_2O, O_2, N_2
Solid phase	Ash, coke	Slag, ash	Ash, slag
Liquid phase	Pyrolysis oil and water		

4. Result & Conclusion:

Kabul city is the largest city and capital of Afghanistan with more than 5 million population as of 2019. The population growth and urbanization rate of the city show a significantly high number and in the recent future by 2025 the population will become around 6 million people with third of the people living in urban areas. Currently generation unit of MSW per capita per day is around 0.5 Kg and it directly increase by improving living standards in the city, as it is estimated that this number will reach 0.6 Kg/c/day by 2025. The collection ratio of MSW in the city is around 70% in 2019 and it is planned to increase to 100% by 2025. In addition there is already about 6 million Tons of MSW stored in Chamtala site of Kabul city.

Considering current situation of the Kabul city and socio-economic conditions of country and by comparing WTE thermal methods, it is concluded that among the three thermal WTE methods, incineration is the only method, which can be applied practically in Kabul city.

Based on this research, our suggestion for government or private sector is to invest in WTE process, in order to overcome the MSW accumulation and open landfill disposal problems in the city, decrease disposal budget of MSW, eliminate hazardous effects of the dangerous components on the environment, and most importantly produce energy (electrical and thermal energy for heating and warm water production purposes). In addition, this project will make job opportunities for hundreds of people directly and indirectly and it will be a good income source for government of Afghanistan in the future.

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